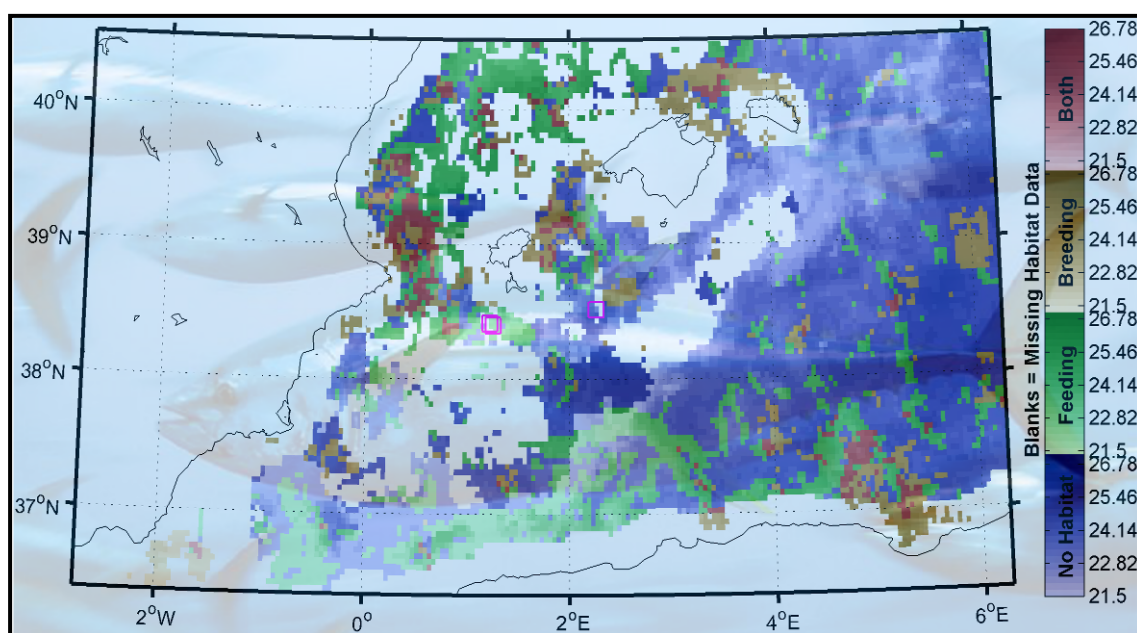


Habitat modelling of marine species derived from satellite data: technical aspects

Documentation of the MATLAB library *Habitat_v1*

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<u>1</u>	<u>INTRODUCTION</u>	<u>5</u>
<u>2</u>	<u>BACKGROUND</u>	<u>5</u>
2.1	FISHERY ISSUES	5
2.2	POTENTIAL CONTRIBUTION OF HABITAT MODELLING	6
<u>3</u>	<u>GETTING STARTED</u>	<u>6</u>
3.1	WHAT IS HABITAT_v1? WHY? HOW?	6
3.2	INSTALLATION	7
3.3	INPUTS	7
3.4	OUTPUTS	8
3.4.1	PRE-PROCESSING (OR INTERMEDIATE DATA)	8
3.4.2	DAILY HABITAT	10
3.4.3	FLOATING HABITAT COMPOSITES (3- AND 7-DAY)	11
3.4.4	TIME-INTEGRATED HABITAT	12
3.4.5	ZOOM ON OBSERVATIONS	13
<u>4</u>	<u>UNDERSTANDING THE PROGRAM STRUCTURE</u>	<u>14</u>
4.1	PROGRAM ORGANISATION	14
4.2	PARAMETERS	18
4.2.1	DEFINITION OF PARAMETERS	18
4.2.1.1	Geographical Area	18
4.2.1.2	Species	18
4.2.1.3	Workspace	19
4.2.1.4	Parameters Which Define the Time Period to Process	20
4.2.1.5	Settings of the Partial Gap Filling	21
4.2.2	DEFINITION OF HABITAT SIZE	21
4.3	PROCESSING STEPS	22
4.3.1	MODEL INITIALIZATION	22
4.3.2	LOADING OF SATELLITE DATA	23
4.3.3	PARTIAL GAP FILLING	23
4.3.4	FRONT PROCESSING AND THRESHOLDING	24
4.3.5	POTENTIAL FEEDING HABITAT	24
4.3.6	TEMPORAL MEANS OF DAILY SST DIFFERENCE	24
4.3.7	USE OF ABSOLUTE SST & CHL-A CONCENTRATION VALUES: 3-DAY COMPOSITES	26
4.3.8	POTENTIAL BREEDING HABITAT	26
4.3.9	HABITAT MERGING FROM TWO COUPLES OF SENSORS	27
4.3.10	BOTH HABITAT AGGREGATION	27
4.3.11	MAPPING THE POTENTIAL HABITATS	28
4.3.11.1	Intermediate Data	28
4.3.11.2	Daily Habitat	28
4.3.11.3	Floating Composites (3- and 7-day)	28

4.3.11.4	Time-Integrated Composites and Associated Coverage	29
4.3.11.5	Zoom on Observations	29
<u>5</u>	<u>PERFORMANCE OF THE HABITAT MODEL</u>	<u>29</u>
5.1	GAIN IN TERM OF COVERAGE	29
5.1.1	GAIN FROM THE PARTIAL GAP FILLING	29
5.1.2	GAIN FROM THE SENSORS' MERGING	32
5.2	PERFORMANCE IN TERM OF HABITAT ESTIMATE	33
<u>6</u>	<u>REFERENCES</u>	<u>34</u>
	<u>APPENDIX - CURRENT PARAMETERIZATION</u>	<u>35</u>

1 Introduction

This report aims at describing in technical terms, as a user manual would do, the MATLAB program “Habitat_v1.m” to derive the potential habitat of targeted marine species. This program has been developed by the JRC – IPSC - Maritime Affairs Unit - FISHREG Action.

After a brief description of current fisheries issues and of potential answers from the habitat modelling, key information to run this program is given. A detailed overview is then made to facilitate future development of the program. Finally, the results of the model performances are presented and discussed.

2 Background

2.1 *Fishery issues*

In 2008, the European Commission declared that 88% of European fish stocks were being overfished compared with only 25% worldwide. Almost one in three fish can't reproduce normally because the parent population is too depleted. This helps explain why Europe - the world's largest fishing power after China – now imports two-thirds of its fish.

This situation partially results from the lack of compliance by Member States for European Regulations. For instance, as of 1 June 2010, the Mediterranean Regulation is fully in force. However, Member States so far have largely failed to take all necessary measures to ensure full implementation. The Mediterranean Regulation takes steps towards mainstreaming environmental concerns into fisheries policy and establishing a network of marine protected areas (MPAs) where fishing activities are restricted to protect nursery areas, spawning grounds and the marine ecosystem. A major problem is the capacity to identify suitable MPAs for species of interest.

The second issue regards illegal fishing which is high especially in remote areas outside EU waters where enforcement is weak. The value of illegal fishing has been assessed to amount worldwide between €7.4 and 17.4 billion. For comparison, the value of landings by the EU fleet was €6.8 billion in 2004. Worldwide level of illegal fishing is estimated to be in the range 8-19% of total catches with significant differences between regions, such as 40% in West Africa. Besides the discrimination from which fishermen operating legally suffer, illegal fishing hampers food security and poverty alleviation in developing countries. The Commission expressed the need to introduce major changes in the EU approach to the monitoring of the legality of fisheries products to be imported into its territory. One aspect of these changes is an increased support for the developing countries to improve control and management in their national waters.

In addition, energy consumption in catching fish is high (e.g. in the range 0.4-1.7 litres of fuel per kg of caught fish for cod and tuna), representing an increasing cost for fishermen and a significant emission of greenhouse gas. The increase of fishery efficiency would thus benefit to the competitiveness of the industry, to its carbon footprint and eventually to the fish stock, if low, by reducing the catch while maintaining the economic viability.

2.2 Potential contribution of habitat modelling

The habitat model of different commercial fish species in near real time (NRT) aims at improving the efficiency of the fishery management and control carried out by Fishery Organizations. The use of habitat mapping in future fishery management could guide in space and time the opening or the closure of grounds to fishing in order to preserve the resource (e.g. avoiding spawning areas). Because the fleet would concentrate in opened areas, the control efficiency by traditional means at sea would raise de facto. While protecting the resource, the NRT habitat maps of the opened area could guide fishermen to the best fishing ground reducing significantly their variable costs (fuel, man-day at sea). See Druon 2010 for details.

The habitat estimation would contribute to balance the social objectives of fisheries with the necessary respect of Regulations and protection of natural resources. This is a high expectation for the European Commission and the Member States. In practical terms, the NRT habitat maps would be sent on a daily basis to Fishery Commissions to exploit preferably healthy fish stocks and guide control operations at sea. The enforcement would become more efficient following the concentration in time and space of the fishing fleet. The sensitive areas of a given species highlighted by the habitat maps would be more actively protected by prohibiting fishing and identifying suitable Marine Protected Areas. In remote areas or outside EU waters, the habitat maps could significantly influence the decision making on where to focus the control (the most important illegal fishing quantitatively is likely to occur in the favourable habitat).

The habitat model is fed daily with sea surface temperature and chlorophyll content from satellite remote sensors. Oceanic features were proved to trace the feeding and spawning habitats of top-predators (bluefin tuna, finback whale). Future developments will transpose the habitat model to other tropical tuna species and/or small pelagic fish (e.g. anchovy, sardine) and/or demersal species (e.g. hake) depending on field data availability. The specific objectives are to enforce fishery control where critical illegal fishing takes place (e.g. in African waters) and to optimize the fishery management by matching in space and time the catch effort to the resource, and the control effort to the fishing fleet. The use of habitat maps in near real time is therefore likely to reduce the three main issues of fisheries (overfishing, illegal fishing and energy efficiency) by providing key spatio-temporal information to management.

3 Getting Started

3.1 What is Habitat_v1? Why? How?

During the past decade, the needs of an increasing global human population have been confronted to the shortage of some natural resources. As for fishery resources, this has led in the last decades to a critical situation for some species like bluefin tuna (BFT) characterized by a drastic decrease of its population. This has led for BFT in the recent years to the creation of fishing quotas followed by their decrease.

The hostile marine environment and the complexity of the ecosystems render difficult the definition of an appropriate plan for fishery regulation both in terms of management and control. In this context, the use of remote sensing allows getting large scale information about ocean features relevant to fish ecology and habitat, especially for highly migratory species such as BFT.

Although the large scale coverage is a great advantage of satellite data, it is dependent on cloud presence. This induces a great variability of available data from one day to another. To cope with this problem several similar sensors on different satellites were launched with different observation times. The advantage of this time shift lies in the variation of the cloud coverage for the same location at a few hours difference (1.5 hours for CHL and 3 hours for SST).

3.2 Installation

Habitat_v1 is organized as a library containing MATLAB functions and sub-programs. Consequently, to run and modify *Habitat_v1* a MATLAB licence is needed. It also requires the *MATLAB image processing toolbox*, the free *MATLAB Google Earth toolbox* and the *M_Map package*¹. Note that the directories of these toolboxes need to be set as path in MATLAB if it is not made automatically.

Then, copy the folder containing the *Habitat_v1* library in the directory of your choice. Set it as a path in MATLAB.

To create a destination directory for all the outputs of *Habitat_v1*, open the M-file *Habitat_Parameter_v1.m* and set the workspace parameter *workdir* with the path of the output folder.

In *Habitat_Parameter_v1.m* set also *datadir* with the path of the folder where all original files can be found, and *tmplocaldir* with the path of a folder where temporary files can be stored during *Habitat_v1*'s run – preferably a folder located on a local hard drive in order to avoid slowing down the run.

```
datadir = K:/SAT_DATA/;  
tmplocaldir = [D:/TEMP_HABITAT/,TmStmp,/];  
workdir = [S:/HABITAT/,species,_HABITAT/];
```

Figure 1: Example of workspace parameter settings.

Habitat_v1 is now installed.

3.3 Inputs

The inputs of the MATLAB code define:

- The species for which the habitat has to be computed, *species*. This input has to be a string of character corresponding to the acronym or name of one of the species handled by the habitat model: BFT stands for bluefin tuna and FBW for finback whale.
- There are two different modes with which it is possible to run the code. The **operational mode** (*operational = true*) in which the time boundaries are predefined to run the code in near real time and the **manual mode** (*operational = false*) in which the user defines the time boundaries of the analysis using the parameters *date_start* and *date_end* defined below.

¹ Download the M_Map package and its documentation at: <http://www.eos.ubc.ca/~rich/map.html>.

- The couple of sensors to use in order to compute the habitat, `sensor`. This input has to be a column-cell vector, with the acronym of the sensor couple(s) handled by the MATLAB code:
 - MAMA stands for the couple Modis-Aqua CHL-a and Modis-Aqua SST (night time 11 μ m), and
 - SeMT for SeaWiFS CHL-a and Modis-Terra SST (night time 11 μ m).

Important note: The sensors' acronyms are four letters in which the two first stand for the CHL sensor and the two last stand for the SST sensor.
- The date of the first and last day of the computing period, `date_start` and `date_end`. These inputs have to be strings of characters with the format *dd/mm/yyyy*. The period defined by `date_start` and `date_end` needs to cover the sensors' lifetime. The number of days which has to be read before (parameter NW and floating composite) has to be taken into account too.
For instance the couple of sensor *SeMT* (SeaWiFS, Modis Terra) can be used only when (`date_start`-NW-2) is greater than the activation of the most recent of the two satellites, in this case Modis Terra in February 2000 (SeaWiFS started to produce data on September 1997).
Modis Aqua was operational on July 2002. All sensors here are still active at the time of this report (June 2010) but only Modis data is available in near real time (SeaWiFS is delivered with a two weeks delay).
- The geographical area of interest: `area`. This input has to be a string of characters and its geographical extension has to be defined in the model. At present, the defined area are:
 - `med` for the Mediterranean;
 - `ne_atl` for North-East Atlantic;
 - `iceland` for Icelandic area;
 - `malta` for Malta to Tripoli area;
 - `w_indian` for Western Indian Ocean;
 - `us` for Gulf of Mexico and Eastern US coast area;
 - `n_europe` for Northern Europe (Irish Sea, English Channel, North Sea, Baltic Sea).

```
species = BFT;
operational = false;
sensor = {SeMT;MAMA} ; % "sensor" has to be a column cell
vector
date_start = 01/06/2004; % "date_start" has to be in the
format dd/mm/yyyy
date_end = 01/30/2004; % "date end" has to be in the
```

Figure 2: Example of "Habitat_v1" input argument settings.

3.4 Outputs

3.4.1 Pre-Processing (or intermediate data)

The pre-processing maps provide an overview of the modification of the original data along the processing chain. Three steps can be visualized with four maps: 1) original

data, 2) result after partial gap filling, 3) result after front computation and 4) result after thresholding.

Gap filled SST and CHL data (`filt_env_data`) and the main fronts (`front.SST` and `front.CHL`) are saved in the intermediate files to avoid repeating the pre-processing unnecessarily.

The mean time gradient over NW days of SST (`m_dtSST`), which is computed later in the program, is appended in the intermediate file in order to be used as background in the zoom-on-observation maps.

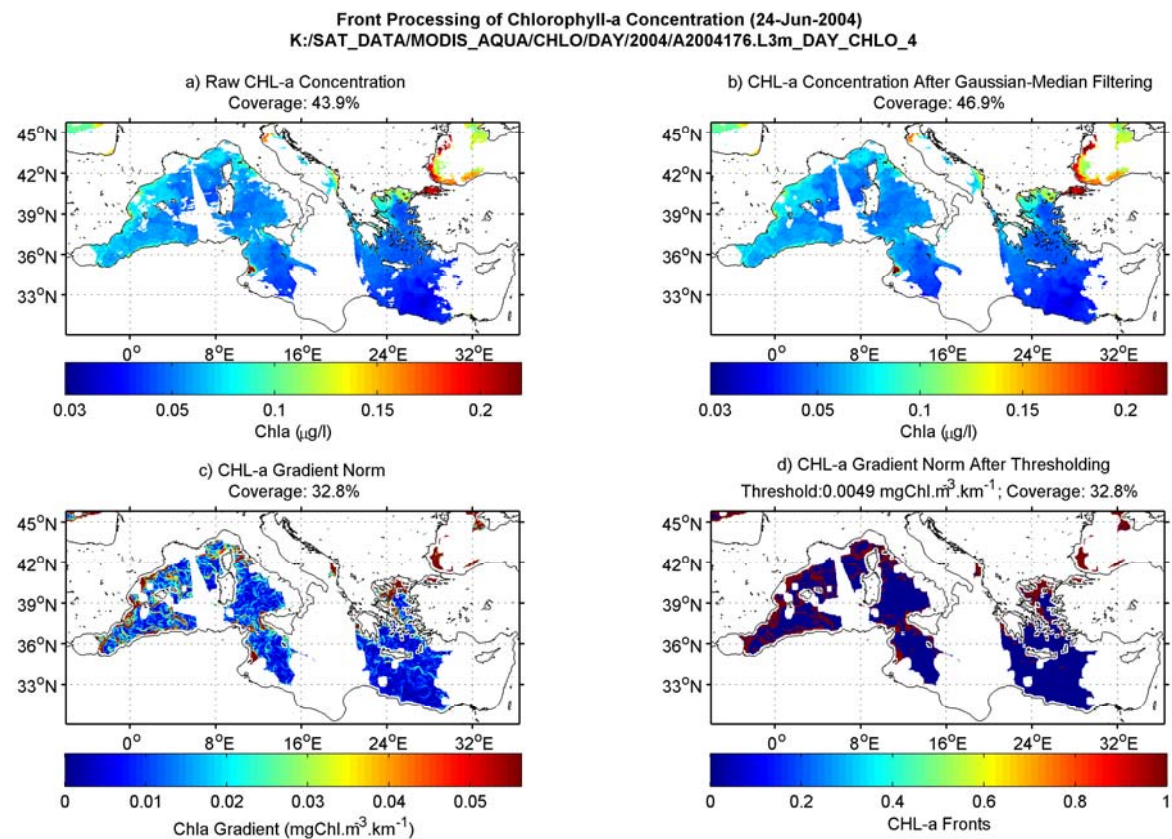


Figure 3: Synoptic of the pre-processing for the CHL-a data of June the 24th, 2004.

Maps can be found at: ***workdir/SST_CHLa_FRONTS/year_area***

Data are located at: ***workdir/SST_CHLa_FRONTS/MAT/area***

Example of directory structure for intermediate outputs in 2002:

S:/HABITAT/BFT_HABITAT/SST_CHLa_FRONTS/2002_med (for maps)

S:/HABITAT/BFT_HABITAT/SST_CHLa_FRONTS/MAT/med (for data)

Note: Some of the intermediate data are dependent on the parameterization. That is why all model parameters are also stored in the intermediate data file. This allows to check if the parameterisation between two runs of *Habitat_v1* has changed, and to re-compute the intermediate files if so.

3.4.2 Daily Habitat

Daily habitat data are stored after computation in order to be accessed easily in an eventual post-processing. Habitat data (FeedingHabitat, BreedingHabitat) are put in 3-dimensional arrays. For a given couple of sensors, the position in the habitat arrays corresponds to the position of its name in the cell-vector `sensor` (Figure 4). FeedingHabitat and BreedingHabitat are attached with the `sensor` cell-vector and saved in a MATLAB file (mat extension).

Each type of habitat, feeding and breeding, is first mapped and saved independently. The feeding and breeding habitat data are then combined in the `BothHabitat` 3-D array and mapped for visualizing their respective daily distribution.

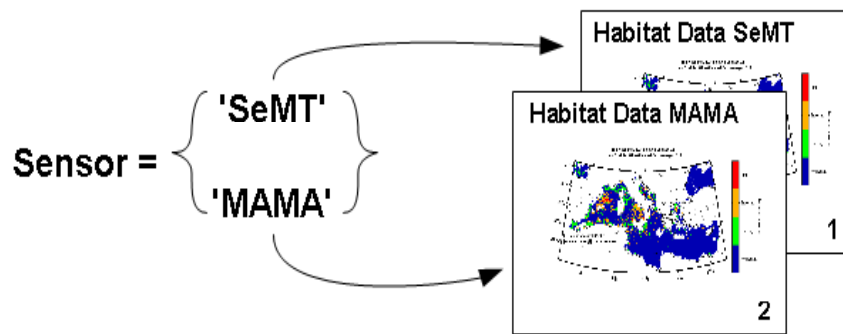


Figure 4: Structure of habitat data files. SeMT = SeaWiFS(CHL)/Modis-Terra(SST) and MAMA = Modis-Aqua (CHL/SST).

Habitat data from the different sensors are then merged and mapped. Merged maps are stored according to the type of habitat (feeding, breeding or both) in the same folders as the single sensor maps.

Location of these outputs:

Habitat Data: ***workdir/TYPOFHABITAT_HABITAT/DAY/MAT_area***

Habitat Map: ***workdir/TYPOFHABITAT_HABITAT/DAY/year_area***

Example of directory structure for the feeding habitat outputs in 2002:

S:\HABITAT\BFT_HABITAT\FEEDING_HABITAT\DAY\MAT_med (for data)

S:\HABITAT\BFT_HABITAT\FEEDING_HABITAT\DAY\2002_med (for maps)

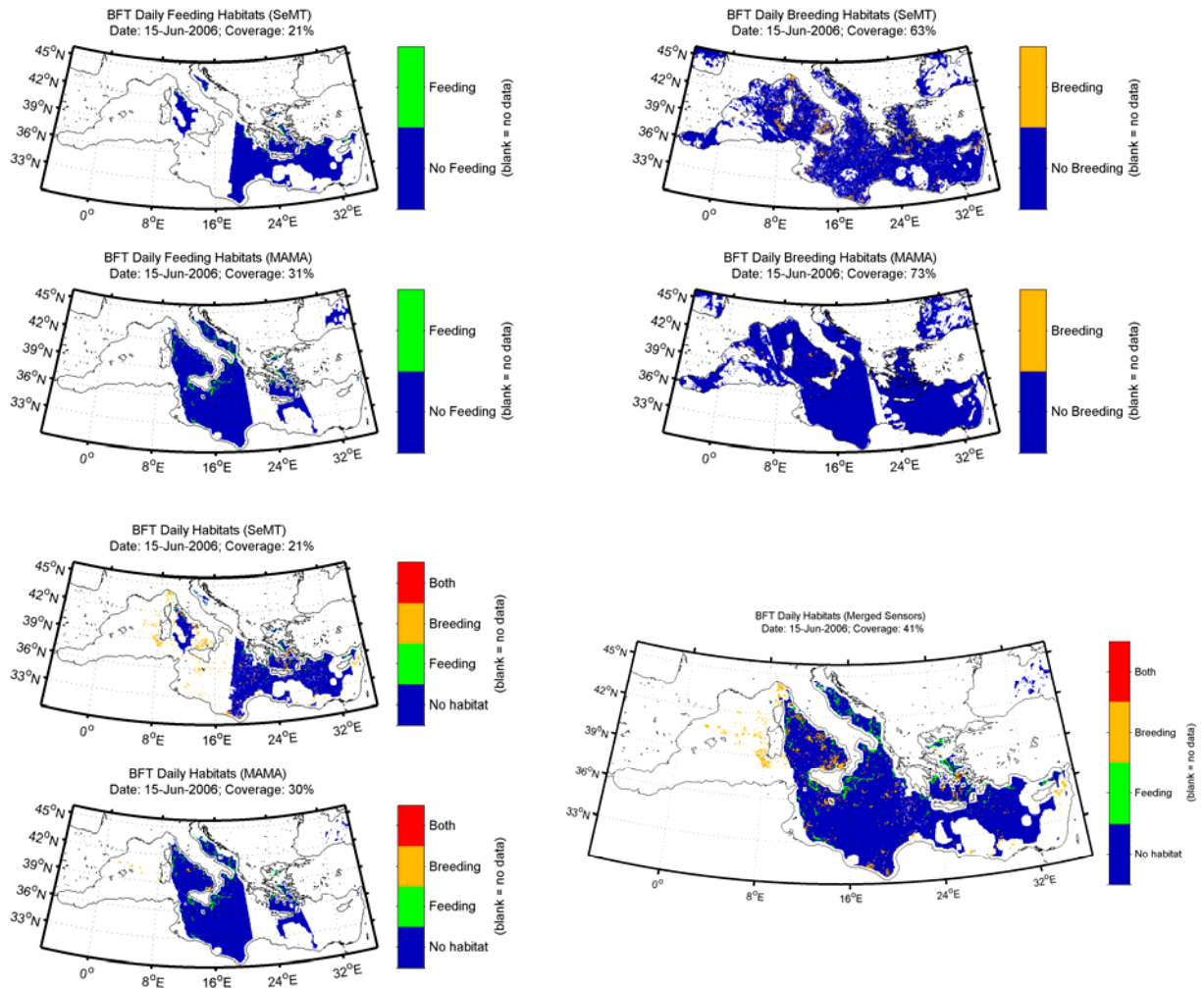


Figure 5: Example of maps produced for June the 15th 2006. Top-left: Feeding habitat from a single couple of sensors. Top-right: Breeding habitat from a single couple of sensors. Bottom-left: Both habitats from a single couple of sensors. Bottom-right: Merging of both habitats from both couples of sensors.

3.4.3 Floating Habitat Composites (3- and 7-day)

Three- and seven-day floating composites for each day and both habitats are produced with the objective to provide an overview of the habitat distribution, particularly in near real time in case of important cloud cover.

These maps can be found at:

Workdir/BOTH_HABITAT/WindowSize/DAY/year_area

Example for a 7-day floating composite in 2006:

S:\HABITAT\BFT_HABITAT\BOTH_HABITAT\7DAY\2006_med

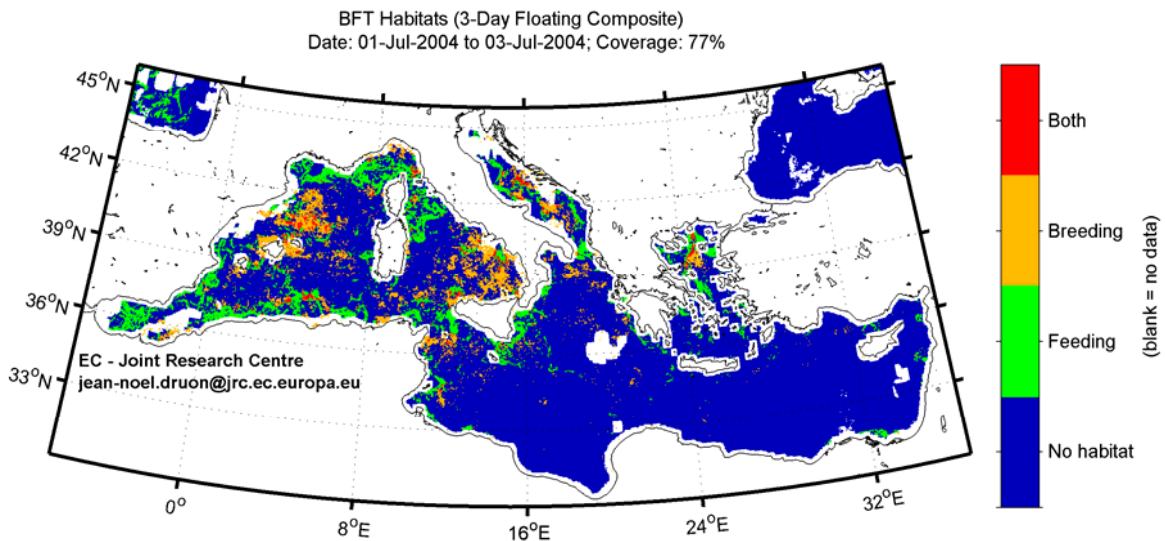


Figure 6: 3-day floating habitat composite for July 1-3 2004. This composite represents the potential habitat of bluefin tuna (BFT): feeding (green), breeding (orange) and both in (red).

3.4.4 Time-Integrated Habitat

Time integrated habitats are composed of two maps presenting the relative habitat occurrence and the coverage percentage for different time scales (fortnight, month, season, and year). These maps are computed separately for the feeding and breeding habitat.

The time-integrated habitat maps are expressed in relative habitat occurrence. It represents the number of days for which a given pixel has been classified as a given habitat over the total number of days for which the habitat was able to be computed. The time-integrated habitat is therefore expressed in percentage.

The time-integrated maps are produced for every fortnight, month, season and year:

- 15-day composites are computed over the period of the 1st to 15th and 16th to 30th/31st of each month.
- Monthly composites are computed from the 1st to the end of each month.
- Seasonal composites are computed between the 1st of January to the 31st of March, between the 1st of April and the 30th of June, from the 1st of July to the 30th of September and from the 1st of October to the 31st of December.
- Annual composites are computed between January 1st and December 31st.

These maps can be found at:

workdir/TYPEOFHABITAT_HABITAT/TYPEOFCOMPOSITE/year_area

Example: For a 7-day floating composite in 2006:

S:\HABITAT\BFT_HABITAT\FEEDING_HABITAT\MONTH\2006_med

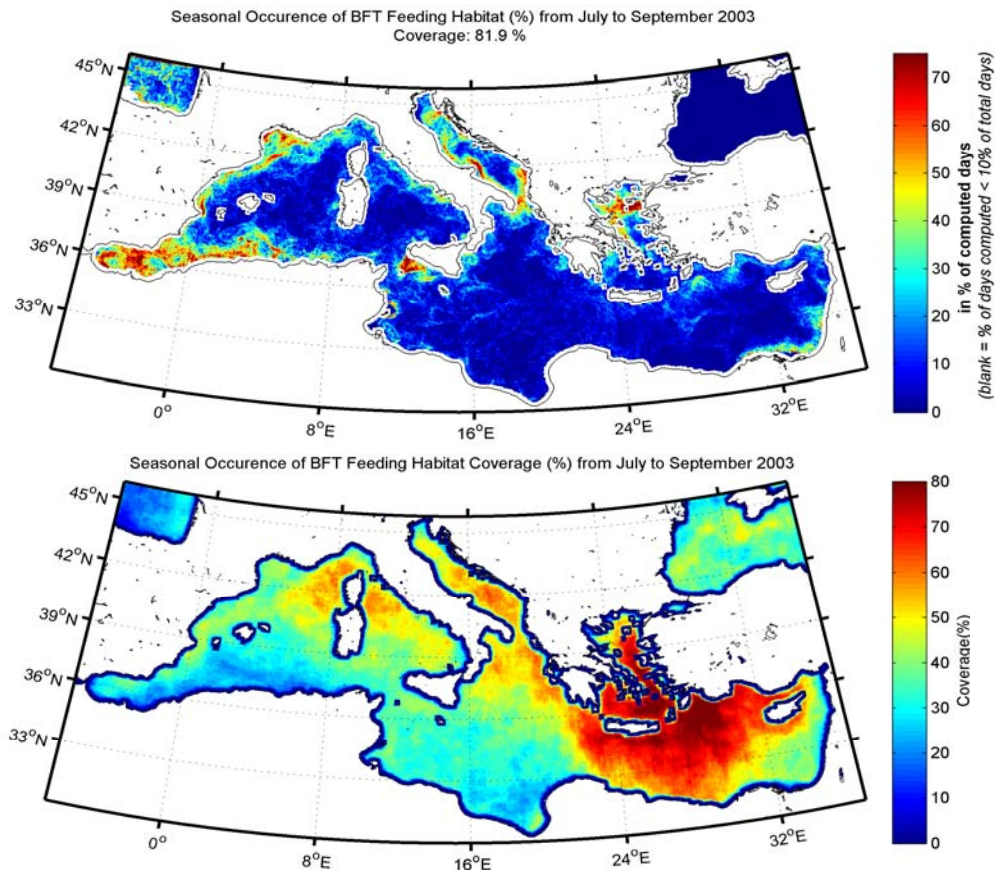


Figure 7: Seasonal composite of blue fin tuna feeding habitat from July to September 2003. Top: Relative occurrence of BFT feeding habitat during summer 2003. Bottom: Relative coverage over July to September 2003. Note the high difference in the distribution of cloud cover.

3.4.5 Zoom on observations

In order to visualize the environmental conditions of each observation, zoomed maps are produced (one per day) showing the habitat with environmental information in shaded background. The main criteria used for deriving the habitat were retained as background variables: SST, Chl-a concentration, SST and CHL front central position, and monthly average of SST increase.

These maps can be found at:

workdir/OBSERVATIONS/

Example: For BFT observations:

S:/HABITAT/BFT_HABITAT/OBSERVATIONS

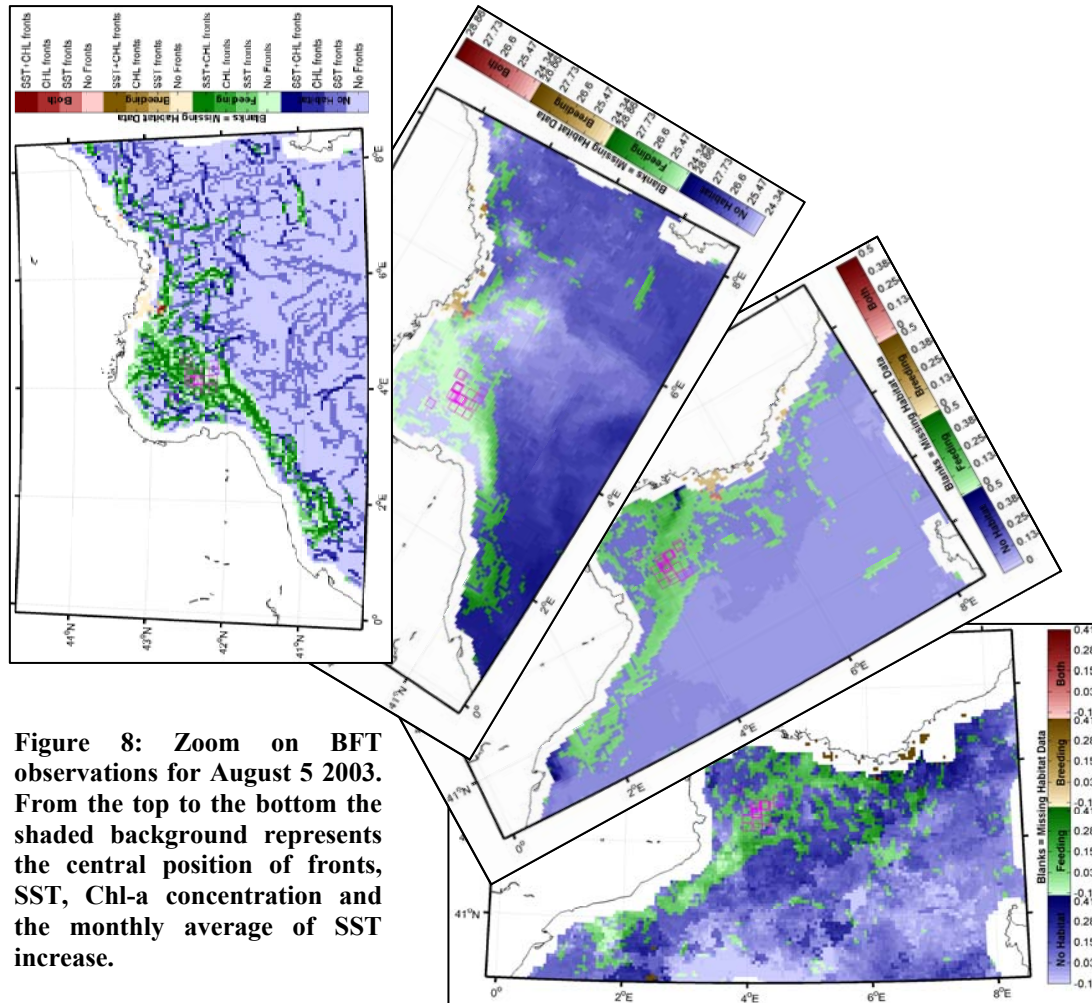


Figure 8: Zoom on BFT observations for August 5 2003. From the top to the bottom the shaded background represents the central position of fronts, SST, Chl-a concentration and the monthly average of SST increase.

4 Understanding the program structure

4.1 Program Organisation

The program is organized in two interlocked loops. The first loop is over the daily files of satellite data. The second loop ensures the processing over the two different couple of sensors.

This structure facilitates the adjunction of a new couple of satellite sensors. To do so, a new string name in the cell array “sensor” has to be added together with slight modifications of the functions in the *Habitat_v1* library.

Note: The reason why there is no loop on variables is because the SST and Chl-a data processing are different. First, they do not have a comparable range of values. Second, the sensors used to measure these variables may require specific processing (e.g. SeaWiFS different resolution). Therefore in order to avoid multiplying the number of *IF* statements and keep the program syntax as clear as possible, we avoided the loop over the variables.

```

- INITIALIZATION (General Variables)

Day loop

  - INITIALIZATION - Day dependant variables

  If Day > date _start_process

    Sensor loop

      - INITIALIZATION - Sensor dependent variables

      If Intermediate file does not exist
      - PARTIAL GAP FILLING
      - FRONT PROCESSING AND THRESHOLDING
      - MAPS - Intermediate File Processing
      Else
      - LOAD INTERMEDIATE FILE
      End

      - FEEDING HABITAT COMPUTATION
      - MAPS - Single Day Habitat

      If NW > 1
      - COMPUTATION OF NW-DAY MEAN OF DAILY SST
      DIFFERENCE
      If NW days already computed
      - 3-DAY SST and CHL DATA INTEGRATION
      - BREEDING HABITAT COMPUTATION
      End
      End

      - BOTH HABITATS COMPUTATION
      - MAPS - Single Day Habitat

    End: sensor loop

    - MERGING OF HABITAT FROM DIFFERENT COUPLE OF SENSORS

    - MAPS - Single Day Habitat

    If the number of computed days is sufficient (3- and
    7-DAY)
    - MAPS - Floating Composite
    End

    If a period of a given time composite is completed
    - MAPS - Non Floating Composite and Associated Coverage
    End

  End: If Day > date _start_process

End: Day loop

- ZOOM ON OBSERVATIONS (It is a special case because it can run independently. Inside the
function the same structure of interlocked loops is present)

```

Figure 9: Habitat_Main_v1 code structure.

The structure of the code intends to respect the following rules for speed and optimization of the memory:

- Avoid repetition of the same calculation and store data that will be used again
- Keep only the necessary data in the live memory
- Avoid loading data from external server more than once

This structure aims at optimizing the memory use and computation time. It allows to process large areas of interest also with modest computing capacities.

Consequently, the breeding habitat is computed as the following:

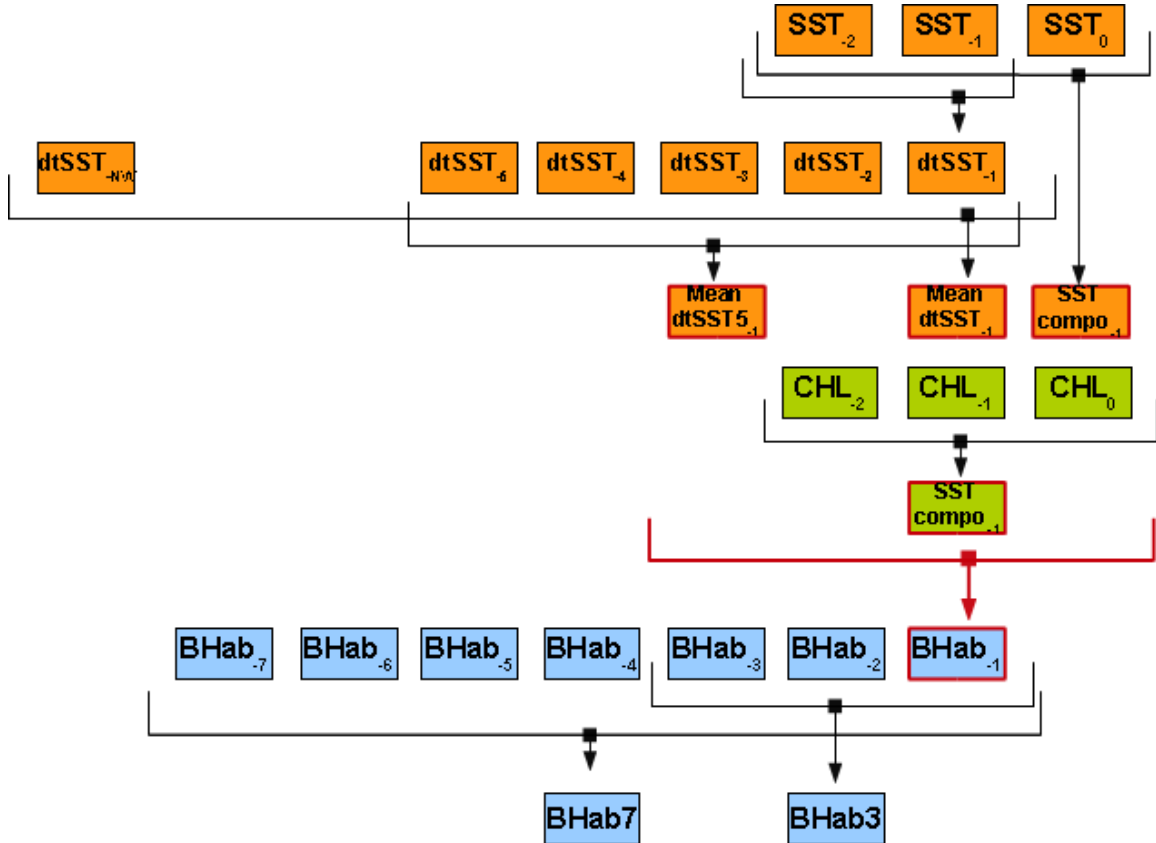


Figure 10: Breeding habitat computation method. Red line boxes are elements needed for the computation of the daily breeding habitat. Orange boxes refer to SST related variables, green boxes refer to CHL related variables and blue boxes refer to daily and floating composites of the breeding habitat.

- Within the daily loop, SST and Chl-a concentration data are loaded or calculated and then placed in separate buffers (SSTbuff and CHLbuff). These buffers contain respectively the SST and CHL data corresponding to the last three iterations of the daily loop.
In Figure 10 the last day data is represented by SST₀ and CHL₀. In the code, environmental data correspond to `filt_env_data.SST` or `filt_env_data.CHL`.
- The SST and CHL data contained in these buffers are then averaged in time over the last three computed days (SSTcompo₋₁ and CHLcompo₋₁ on Figure 10, SSTComposite3 and CHLComposite3 in the code).

- The last daily SST temporal gradient ($dtSST_{-1}$ on Figure 10, $dtSST$ in the code) is computed from the two first elements of the SST buffer (SST_{-1} and SST_{-2}).
The mean of the SST temporal gradient over NW days (from current day -NW to current day -1) and the 5 day (from current day -5 to current day -1) are then computed as explained in section 4.3.6 .
- The habitat corresponding to the iteration day-1 (BH_{-1} on Figure 10 and `BreedHabitat` in the code) can be computed and placed in the breeding habitat buffer, `BREEDHABbuff` in the code.
- Finally, the 3-and 7-day floating composites of breeding habitat are computed from `BREEDHABbuff`. They are respectively centred on the day -2 and -4 compared to the current iteration (day 0). 3-day composites correspond to BH_{-3} on Figure 10 and `BreedFComp3` in the code; and 7-day composites to BH_{-7} on Figure 10 and `BreedFComp7` in the code.

The feeding habitat is computed as the following:

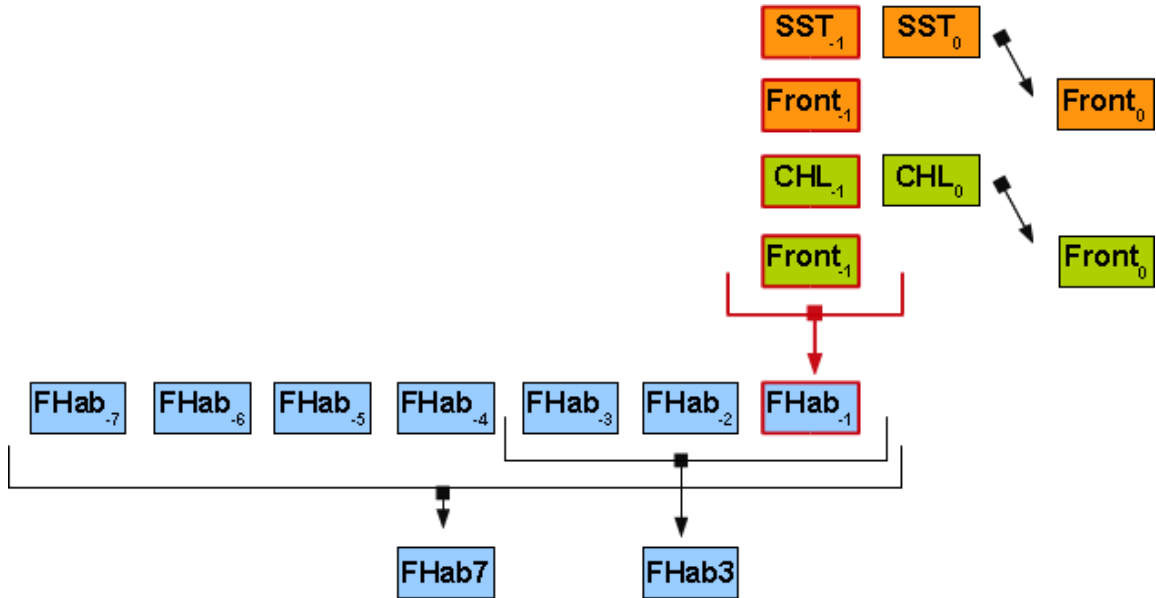


Figure 11: Feeding habitat computation method. Red line boxes are elements needed for feeding computation. Orange boxes refer to SST related variables, green boxes refer to CHL related variables and blue boxes refer to habitat variables.

- Within the daily loop, SST and Chl-a concentration data are loaded or calculated and then placed in separate buffers (`SSTbuff` and `CHLbuff` in the code) which contain respectively the SST and CHL data corresponding to the last three daily iterations.
On Figure 11 the current daily data are represented by SST_0 and CHL_0 . In the code, environmental data correspond to `filt_env_data.SST` and `filt_env_data.CHL`.
- Since the information on fronts is computed and saved in the RAM during the previous iteration, the previous-day habitat (FH_{-1} on Figure 11 and `FeedHabitat` in the code) can be computed and placed in the feeding habitat buffer `FEEDHABbuff`.

- SST and CHL front data (Front on Figure 11 and `front.SST` and `front.CHL` in the code) which were loaded or computed a little earlier in the code (see paragraph 4.3.4) can now be placed in the buffer `SSTfronts_1` and `CHLfronts_1` in order to be used during the next iteration.
- Finally, the 3- and 7-day floating composites of feeding habitat are computed. They are respectively centred on the day -2 and -4 compared to the current iteration (day 0). 3-day composites correspond to `FHab3` on Figure 11 and `FeedFComp3` in the code; and 7-day composites to `FHab7` on Figure 11 and `FeedFComp7` in the code.

4.2 Parameters

All parameter values of the current parameterization are in Appendix 0.

4.2.1 Definition of Parameters

4.2.1.1 Geographical Area

The original satellite data downloaded from NASA cover the global ocean. The area of interest is selected using the input parameters. These regions currently are:

- The Mediterranean Sea, 'med',
- Malta to Tripoli area, 'malta',
- North-East Atlantic, 'ne_atl',
- Western Indian Ocean, 'w_indian',
- Iceland, 'iceland',
- Gulf of Mexico and Eastern US coast area, 'us',
- Northern Europe (Irish Sea, English Channel, North Sea, Baltic Sea), 'n_europe',

The geographical extension of each region is contained in `LATLIMS` and `LONLIMS`. These are 2-elements vectors in which the first element corresponds to the lower limit and the second element to the upper limit of latitude [-90, 90] and longitude [-180, 180].

4.2.1.2 Species

This parameter selects the species of interest. In this version, species can be either: 'BFT' (bluefin tuna), OR 'FBW' (finback whale).

A specific set of parameters corresponds to a given species. In other words, specific environmental conditions and oceanic features were identified to efficiently trace a given habitat of a particular species (Druon et al., in prep.).

BREEDING HABITAT PARAMETERS:

- `NW`: number of days over which the mean daily SST difference (`m_dtSST`) is computed.
- `frac_NW`: minimum fraction of the `NW` days required to compute breeding habitat. Below this minimum number of days, the computed surface heating is not considered as representative of the previous `NW` days.

- `dsstbreed`: Minimum required mean temperature increase m_dtSST (in °C/day).
- `chl_breed_min`: Minimum required Chl-a concentration value (in mg/m^3).
- `chl_breed_max`: Maximum required Chl-a concentration value (in mg/m^3).
- `Tminbreed`: Minimum required SST value (in °C).

FEEDING HABITAT PARAMETERS:

The parameters used to compute the horizontal gradient (Canny filter) characterize a calculation along the lines (x-direction) and along the columns (y-direction).

X-axis direction filter:

- `Nxy`: Size in pixels of a square window used to compute the Canny filter.
- `Nx1`: First dimension (number of rows) of the Canny filter window in pixels. It equals `Nxy` in practice.
- `Sigmax1`: Standard deviation of the Gaussian low-pass part of the Canny filter in pixels along the first dimension (lines).
- `Nx2`: Second dimension (number of columns) of the Canny filter window in pixels. It equals `Nxy` in practice.
- `Sigmax2`: Standard deviation of the Gaussian low-pass part of the Canny filter in pixels along the second dimension (columns).
- `Theta1`: Direction of the edge detection in radians. For gradient computation following the lines the value of theta is $\Pi/2$ (90°).

Y-axis direction filter:

The filter along the second dimension (columns) has the same parameterization than along the first dimension: `Ny1`, `Sigmay1`, `Ny2`, `Sigmay2`, except for the orientation `Theta2` which has to be perpendicular to the previous one, i.e. equals to 0.

- `levels`: 2-element vector containing the thresholding values for the horizontal fronts. The SST threshold is the first element and CHL threshold is placed in second. They are respectively expressed in °C/km and $mg/m^3/km$.
- `chl_feed_min`: Minimum required Chl-a concentration value (in mg/m^3).
- `chl_feed_max`: Maximum required Chl-a concentration value (in mg/m^3).
- `Tminfeed`: Minimum SST value required for a pixel to be classified as feeding habitat.

4.2.1.3 Workspace

To manage all inputs and outputs, all the work space is parameterized.

- `workdir`: This is the directory where all the products corresponding to a given species are saved. For example:
`workdir = 'S:/HABITAT/BFT_HABITAT/'`
- `tmplocaldir`: This directory is a folder on the local drive where it is possible to store data and results temporarily. This directory is then deleted at the end of a completed run of `Habitat_Main_v1`.

Note: It is necessary to include the date of creation in the file name to be able to run `Habitat_Main_v1` several times at once. Otherwise, the two different

runs would use the same folder and interfere with the data of each other. For example to store temporary data on the local drive D:

```
tmplocaldir = ['D:/TEMP_HABITAT_', TmStmp, '/'];
```

- **datadir:** This folder is the place where all the original satellite data are stored.
- **sharedmatdir:** In this folder lie all the common information to all species. For example, the area-linked files such as latitude and longitude grids, pixels size, landmask, bathymetry, etc. or even the date of the last successful run of `Habitat_v1`.
- **outdirbothgoogle:** This is the directory where all the Google Earth-formatted maps (KMZ-files) are stored.
- **outdirfronts:** Directory where the intermediate files and corresponding maps are stored.
- **outdirfeed:** Directory where all the feeding maps and data are stored.
- **outdirfeed15d:** Directory where all the 15-day composites maps and the associated coverage maps of feeding habitat are stored.
- **outdirfeed30d:** Directory where all the monthly composites maps and the associated coverage maps of feeding habitat are stored.
- **outdirfeed90d:** Directory where all the seasonal composites maps and the associated coverage maps of feeding habitat are stored.
- **outdirfeed300d:** Directory where all the annual composites maps and the associated coverage maps of feeding habitat are stored.
- **outdirbreed:** Directory where all the breeding maps and data are stored.
- **outdirbreed15d:** Directory where all the 15-day composites maps and the associated coverage maps of breeding habitat are stored.
- **outdirbreed30d:** Directory where all the monthly composites maps and the associated coverage maps of breeding habitat are stored.
- **outdirbreed90d:** Directory where all the seasonal composites maps and the associated coverage maps of breeding habitat are stored.
- **outdirbreed300d:** Directory where all the annual composites maps and the associated coverage maps of breeding habitat are stored.
- **outdirboth:** Directory where all the both habitats maps and data are stored.
- **outdirboth3d:** Directory where all the 3-day floating composites maps and the associated coverage maps of both habitats are stored.
- **outdirboth7d:** Directory where all the 7-day floating composites maps and the associated coverage maps of both habitats are stored.
- **outdirrobs:** Directory where all the maps of zooms around observation are stored.

In the output directories, maps and data are organised following the type of output, the type of habitat, the area represented and the year. All datafiles are located in folder with names containing “MAT”.

4.2.1.4 Parameters Which Define the Time Period to Process

For a given species, NW might change depending on which couple of sensors is used (calibration-dependent). In practice, NW equals 30 for both couples of sensors for BFT (note that the default value in case breeding is not computed, i.e. for FBW, has to

be 1). Consequently, the date of the processing start might be changed as it is a function of NW. Therefore to cope with these different start dates, the following time parameters have to be set.

The date of the processing start, `date_start_process`, can be different for each couple of sensors because they might not require the same NW. This date corresponds to the first day needed in the computation of the 7-day floating composite centred on `date_start` (defined in input of `Habitat_Main_v1`, see paragraph 3.3). Therefore:

$$date_start_process = date_start - 3 - (NW - 1) = date_start - (NW + 2)$$

Once these dates have been computed for every couple of sensors, the loop then starts on the oldest date, `date_start_loop`.

The last computation day of the loop, `date_end_loop`, is chosen to allow computing until the 3-day floating composite centered on `date_end` (defined in input of `Habitat_Main_v1`, see paragraph 3.3):

$$date_end_loop = date_end + 1$$

4.2.1.5 Settings of the Partial Gap Filling

The parameters of the Order-Gauss filter which is used for the partial gap filling are:

- `SzOrd`: Size of the order filter.
- `Perc`: Percentile of the order filter.
- `SzGauss`: Size of the low-pass Gaussian filter.
- `SigGauss`: Standard deviation of the low-pass Gaussian filter.

4.2.2 Definition of Habitat Size

Unlike most of the habitat models which are inferring habitat areas directly from the oceanic conditions at the place of the observations, the habitat model in `Habitat_v1` is a model of habitat centred on oceanic structures. Observations are only used to calibrate the model.

Using a minimization function taking into account the distances between the observations and the closest habitat, the model parameters are calibrated (front threshold, SST and Chl-a concentration range, period of time for the integration of SST temporal gradient, etc.). These parameters allow to identify oceanic structures of main interest for the habitat of the studied species as well as to define its spatial extension.

The definition of the model is explained in Druon *et al.*, in prep.

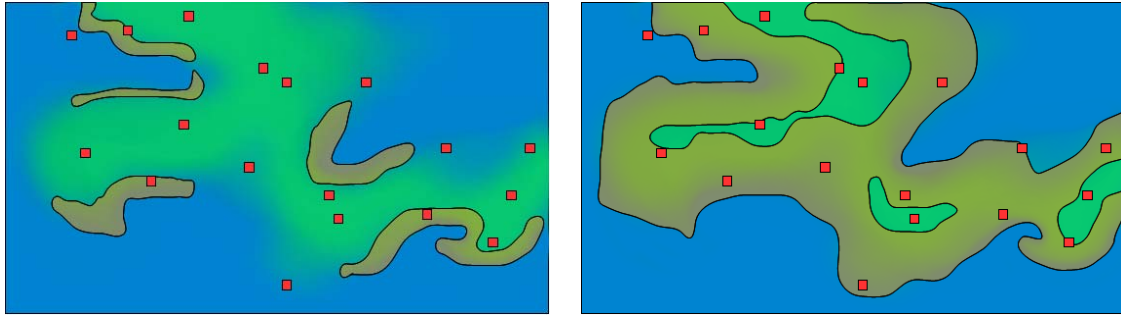


Figure 12: Habitat calibration from the observations. Two different possibilities to map habitat around oceanic structures of many are shown. The calibration aims to find the habitat contours which represent the best compromise between the size of the habitat and the mean distance separating the observations outside the habitat to the closest habitat contour.

The MATLAB code used for the calibration, `all_species_obs2hab_performance`, is located in the folder: *workdir/./HABITAT/MATLAB*.

4.3 Processing Steps

Note: A help on the functions used in `Habitat_v1` can be found at the beginning of each program or by typing: `help NameOfFunction`, in the MATLAB Command Window.

4.3.1 Model Initialization

The program starts by loading the input parameters and checking their values. The other parameters (relative to species, area, satellites, computer, etc.) are then loaded. A list of days, `ListDays`, is then created to define the days required for the habitat calculation (from `date_start_loop` to `date_end_loop`). The day loop will be based on this list.

The availability of all the original files in the archive on the `SAT_DATA` common drive is verified. The intermediate files computed in the last 20 days prior the last successful run of the `Habitat_v1` code are then removed to be updated later in the code. This recalculation module was implemented to ensure that the potentially incomplete satellite data provided in near real time will be effectively reprocessed once downloaded again about two weeks after the day of observation.

The functions used for the initialization are listed below in chronological order of use in the code:

```
Habitat_DispInputs_v1
Habitat_Parameter_v1
    Habitat_GetGeoScalSatAttribute_v1
    Habitat_GetLandNoDataMask_v1
Habitat_TestInputs_v1
Habitat_CheckArchive_v1
    Habitat_ProcessList_v1
Habitat_CreateOriginalFilePath_v1
Habitat_RmLastFrontFiles_v1
Habitat_ProcessList_v1
```

4.3.2 Loading of Satellite Data

Daily SST, CHL, horizontal gradient of SST and CHL are needed for the daily habitat computation. If the intermediate file containing these data already exists and was computed with the same parameterization (checked by `Habitat_ParamCmp_v1`), the intermediate data are directly loaded. In this case, the processing directly computes the mean temperature difference over NW days (see paragraph 4.3.6).

If the intermediate file was not computed, the program loads the original data available on the `SAT_DATA` hard drive in HDF format (`Habitat_GetOrigEnvData_v1`). The data are then pre-processed to create intermediate data (see paragraph 3.4.1 and **Error! Reference source not found.**).

4.3.3 Partial Gap Filling

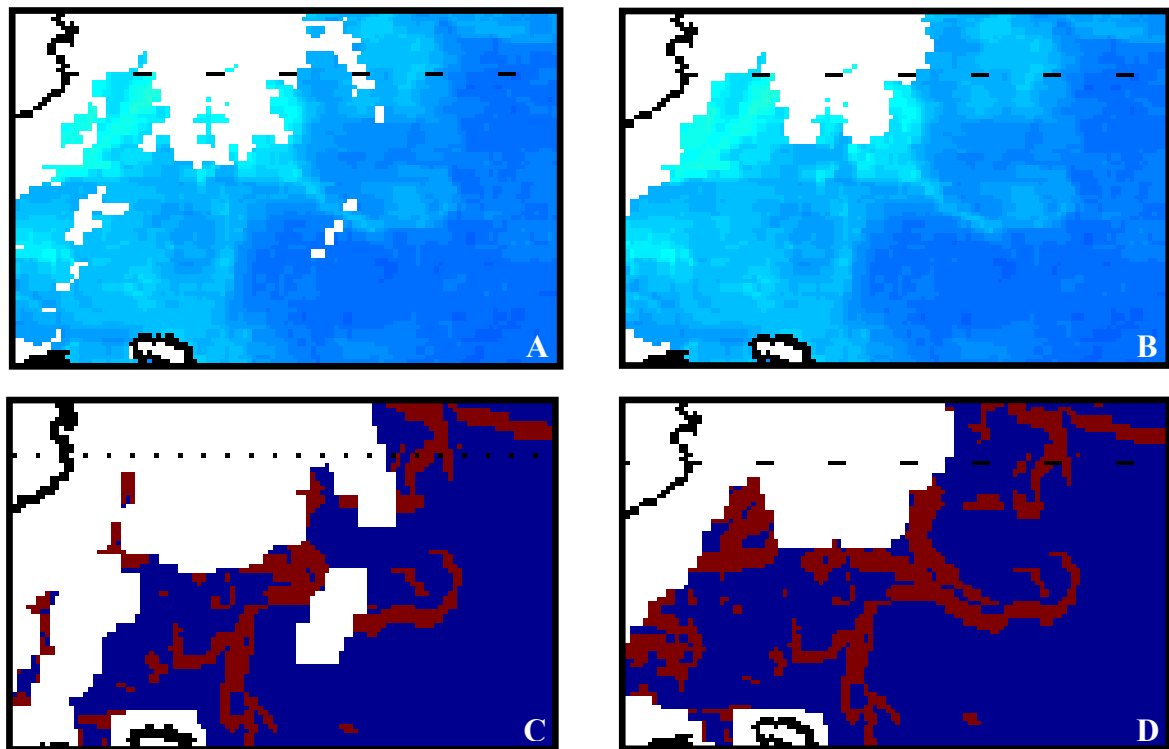


Figure 13: Effect of gap filling on Chl-*a* concentration data and on Chl-*a* front. The top figures represent Chl-*a* concentration before (A) and after gap filling (B). The bottom figures (C and D) are the fronts computed from Figure A and B (respectively without and with gap filling).

Cloud cover affects SST and CHL measurements. The loss of coverage becomes important when it comes to compute the horizontal gradient of these variables. Indeed the Canny filter is applied on a 7-by-7 square window which leads to a loss of 3 pixels around a gap in original data. Consequently, data reconstruction is made to fill relatively small gaps in data (a maximum of 12 pixels wide).

The method aims to give maximum importance to original data by resetting original data where it was present originally after each of the ten iterations of the 5-by-5 median filtering and after the final smoothing by a 3-by-3 Gaussian filter.

This gap filling operation is made by the function:

`Habitat_OrderGaussFilt_v1.`

4.3.4 Front Processing and Thresholding

The feeding habitat is mainly based on simultaneous occurrence of significant SST and CHL fronts (`Front.SST` and `Front.CHL`, see Druon *et al.* in prep. for details). If the fronts are not loaded from the intermediate files, their computation is made with a N_{xy} -by- N_{xy} pixels Canny filter, i.e. Gaussian filtering (smoothing) followed by Sobel filtering (gradient). In the current parameterization, N_{xy} is 7 (pixels). To focus on the main oceanic characteristics, a selection of the most important fronts is made by thresholding the horizontal gradient norm.

Gradient processing is computed by `Habitat_FrontProcessing_v1` which is using the MATLAB function `d2gauss`. The thresholding is then made by `Habitat_Thresholding_v1`, leading to SST and CHL fronts.

The horizontal gradients of importance for the habitat are stored in the intermediate files in a “binary” format (i.e. 0, 1 or NaN, see paragraph 3.4.1).

4.3.5 Potential Feeding Habitat

Note: The notion of potential habitat here is opposed to the effective habitat. Because the favourable environmental conditions are used to identify the preferred habitat and because the targeted population is not homogeneously distributed over this habitat, we define the results as potential habitat.

Both SST and CHL fronts are needed to compute the feeding habitat together with surface chlorophyll concentration. These conditions aim to determine oceanic areas where the development of the food web is sufficient to provide food to the targeted species, but also provide suitable conditions for the specific feeding behaviour. In the case of BFT, the relatively low chlorophyll concentration allows the hunting by sight (see Druon 2009 and 2010 for criteria and literature review).

The habitat is then computed following these rules:

- Presence of relevant SST front;
- Presence of relevant CHL front;
- Chlorophyll concentration included in the range `chl_feed_min`, `chl_feed_max`. It is the criterion which gives a proxy of the potential presence of preys (e.g. mainly small pelagics). (See corresponding parameters’ description in 4.2.1 and values in Appendix 0)

For each sensor, the habitat data are stored and mapped (see 4.3.11.2) followed by daily merged maps. For locations of the habitat map and data, see section 3.4.2 .

This step is made by the function `Habitat_CreateFeedingHabitat_v1`.

4.3.6 Temporal Means of Daily SST difference

The computation of BFT breeding habitat is based on the presumption that BFT seeks for a stabilized stratification to spawn, providing suitable conditions for larvae survival. The mean of the daily increase of SST over NW and 5 days are used as a proxy of the stabilization of the surface water column during spring.

First, the mean of the daily variation of SST over NW days (`m_dtSST`) is computed if the minimum fraction `frac_NW` of temperature differences is reached.

How is this computation made?

When the value of NW is important (as currently equals to 30 days), the amount of data needed to compute m_dtSST may exceed the memory capacity. This is the reason why some data have to be saved temporarily on the local hard drive (`tmplocaldir`).

The method to compute the temporal mean is based on two matrices of the same size as the geographical grid of the area, which are incremented or decremented with the appropriated data:

- the sum of the finite values of $dtSST$ over NW days: s_dtSST ;
- and the number of finite values of $dtSST$ over NW days: ctr_dtSST ;

SST_D is the value of one pixel of SST for the day D where $D=0$ is the current processed day. For a given pixel, $dtSST$ is computed first:

$$dtSST_0 = SST_0 - SST_{-1}$$

If $dtSST_0$ has a finite value, it is added to s_dtSST and ctr_dtSST is incremented. The $dtSST$ already saved on `tmplocaldir` (corresponding to the NW^{th} day prior the current processing day) is subtracted to s_dtSST to adjust the sum over NW days. The counter ctr_dtSST is in parallel adjusted accordingly:

$$\text{If } dtSST \text{ is finite: } s_dtSST_0 = s_dtSST_{-1} + dtSST_0 - dtSST_{-NW};$$

$$\text{and } ctr_dtSST_0 = ctr_dtSST_{-1} + 1 - ctr_dtSST_{-NW}.$$

$$\text{If } dtSST \text{ is not finite: } s_dtSST_0 = s_dtSST_{-1} + 0 - dtSST_{-NW};$$

$$\text{and } ctr_dtSST_0 = ctr_dtSST_{-1} + 0 - ctr_dtSST_{-NW}.$$

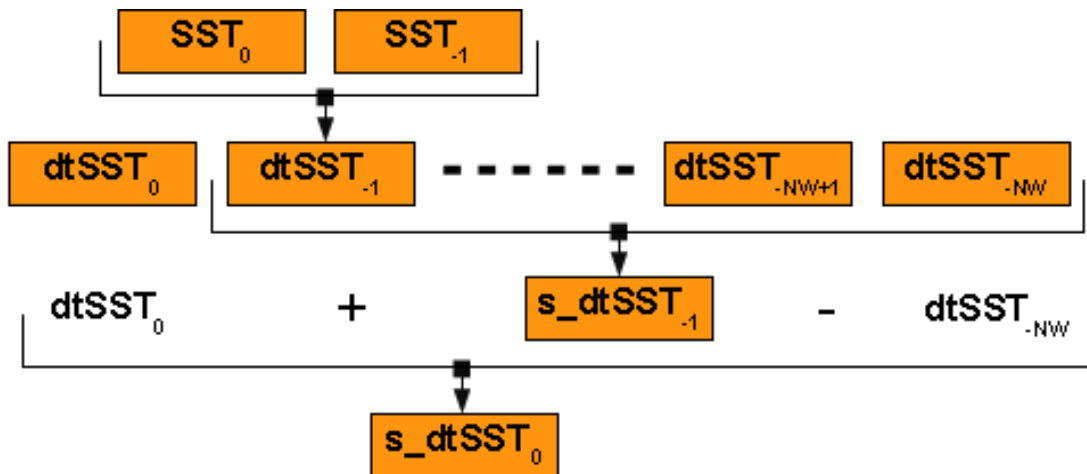


Figure 14: Scheme describing the calculation of s_dtSST .

The computation of the mean SST difference over NW days is computed by dividing s_dtSST by ctr_SST element by element.

$$m_dtSST_0 = s_dtSST_0 / ctr_dtSST_0.$$

At the end of the computation, `dtSST` and the position of finite value of the `dtSST` are saved temporarily on `tmplocaldir` to be subtracted to `s_dtSST` and `ctr_dtSST` NW time steps (days) later.

The mean of `dtSST` over 5 days is calculated similarly.

Note: In the code, SST value are contained in `filt_env_data.SST` and `SSTbuff`,

Finally, `m_dtSST` is saved in the intermediate file corresponding to the last day taken into account. For the location of intermediate files, see paragraph 3.4.1 .

4.3.7 Use of Absolute SST & Chl-a Concentration Values: 3-Day Composites

Prior to compute the breeding habitat, SST and Chl-a concentration data are integrated over 3-days. As these environmental variables generally show a low variability within 24 hours, data of the previous day and of the following day are integrated in order to gain coverage. Current day data are over imposed on the resulting 3-day mean to use the closest measurement to compute the daily habitat. Only the absolute values of 3-day SST and Chl-a composites are used in the habitat calculation. Neither horizontal nor temporal gradient are computed with these composites.

This step is made with the `Habitat_EnvDataComposite_v1` function.

4.3.8 Potential Breeding Habitat

In the current model, the breeding habitat is only computed for BFT. The conditions for the BFT to breed are a minimum temperature and a stable stratification (Druon *et al.* in prep.). A calm weather condition is also needed as well as favourable feeding condition for the larvae.

Below are summarized the used criteria for the spawning habitat:

- A temperature greater than `Tminbreed`.
- A temperature increase in the last NW days greater than `dsstbreed`. This criterion reflects an important heating of surface waters.
- A positive mean increase of temperature over the last 5 days. This reflects calm weather conditions and recent heating.
- A chlorophyll concentration in the range from `chl_breed_min` to `chl_breed_max`. This is a proxy of the food availability for the larvae (Druon 2010 and 2009).

All parameters are described in section 4.2.1 and values in Appendix 0.

This step is computed by the function `Habitat_CreateBreedingHabitat_v1`.

4.3.9 Habitat Merging from Two Couples of Sensors

In order to increase the coverage, habitat data are computed using sensors observing the sea surface at different time of the day or night. Currently Modis aqua Chl-a concentration and SST on one hand, and SeaWiFS Chl-a concentration and Modis Terra SST on the other hand are used. Both Chl-a observations are made 1.5 hours apart (10.30 and 12.00 GMT) and both SST observations have a 3-hour time shift (22.30 and 01.30 GMT).

As habitat data are calculated independently with data of both couple of sensors – due to generally slight inconstancies of their respective absolute values – habitat data are merged in a single map at the end of the processing (see an example on the bottom maps in Figure 5).

This operation is made regarding the following rules:

- Habitat + Habitat / Non Habitat / Missing data = Habitat;
- Non Habitat + Non Habitat / Missing data = Non Habitat;
- Missing data + Missing data = Missing data.

The next table show the percentage of pixels that were classified differently (mainly habitat/no habitat) by SeaWiFS/Modis Terra and Modis Aqua. The low percentage of difference between the two couple of sensors (about 10%) allows the merging of both estimates.

Habitat type	SeaWiFS/Modis-Terra vs Modis-Aqua difference
Feeding (annual)	11 %
Breeding (May-July)	5 %

Table 1: Classification difference (mainly habitat/no habitat, in %) of the model using SeaWiFS/Modis-Terra and Modis-Aqua.

The habitat merging is done by the function `Habitat_HabMerg_v1`.

All these data are saved and mapped (see section 3.4.2).

4.3.10 Both Habitat Aggregation

To summarize data of both type of habitat in a single map, the “both habitats” data set is created and mapped (see 3.4.2). For doing so, the value 0 is given to the non habitat, 1 to the feeding habitat, 2 to the breeding habitat, 3 to both habitats and NaN to missing data.

The combination of the two types of habitat obeys to the following rules:

- Feeding habitat (1) + Breeding habitat (2) = Both habitats (3);
- Breeding habitat (1) + Non feeding habitat (0) = Breeding habitat (2);
- Feeding habitat (1) + Non breeding habitat (0) = Feeding habitat (1);
- Missing data (NaN) + Non Feeding habitat (1) or Non Breeding habitat (2) = Missing data (NaN).
- Missing data (NaN) + Feeding habitat (1) or Breeding habitat (2) = Feeding habitat (1) or Breeding habitat (2)

All these rules are summarized in the following table:

	NaN = No Data	0 = Non Feeding Habitat	1 = Feeding Habitat
NaN = No Data	NaN = No Data	NaN = No Data	1 = Feeding Habitat
0 = Non Breeding Habitat	NaN = No Data	0 = Non Habitat	1 = Feeding Habitat
2 = Breeding Habitat	2 = Breeding Habitat	2 = Breeding Habitat	3 = Both Habitats

Table 2: Rules used to compute the combination of both types of habitat.

This operation is made using the function: `Habitat_BothHab_v1`.

4.3.11 Mapping the Potential Habitats

In order to map geo-referenced data with Matlab, the toolbox `M_Map` is needed (freely available at: <http://www.eos.ubc.ca/~rich/map.html>).

4.3.11.1 Intermediate Data

Intermediate file maps are made to visualize the different steps of the pre-processing and front computation. It is done with two different functions which are dealing specifically with SST data and Chl-a concentration data:

- `Habitat_MapSSTProcessing_v1`;
- `Habitat_MapCHLProcessing_v1`.

Note: Two different functions are needed because the units as well as the legends are different in the two cases. In order to increase the clarity (without adding too many *if* statement and loops) of the main script these functions were separated in spite of the fact that their script are quite similar.

4.3.11.2 Daily Habitat

The two functions used to create these maps are:

- `Habitat_Map1Hab_v1`, which is used to map EITHER feeding OR breeding habitat SEPARATELY. On this kind of maps, feeding habitat is represented by green pixels whereas breeding habitat is represented by orange pixels.
- `Habitat_Map2Hab_v1`, which is used to map both habitats on the same figure. These maps contains 4 different colours: white, blue, green, orange and red, respectively corresponding to missing data, non-habitat areas, feeding areas, breeding areas and areas classified as feeding and breeding at the same time.

For more detailed technical information, see the MATLAB code help.

4.3.11.3 Floating Composites (3- and 7-day)

Floating composite maps are made for periods of 3 and 7 days centred on the current day of computation. These maps compile or add habitat data over several days following the same rules as data merging (see 4.3.9). The computation of floating

composites is done by the function `Habitat_HabMerg_v1` and mapped with the functions `Habitat_Map1Hab_v1` and `Habitat_Map2Hab_v1`.

4.3.11.4 Time-Integrated Composites and Associated Coverage

Non-floating composites are made for periods of 15 days, one month, one season and one year. A map is made for one kind of habitat at a time, either feeding OR breeding. Composites represent the ratio between the number of days classified as feeding or breeding habitat (Day_{hab}) and the number of days for which the habitat estimation was possible (Day_{data}) during the considered period of time (T_{compo}).

$$\frac{Day_{hab}}{Day_{data}} \text{ during } T_{compo}$$

When Day_{data} / T_{compo} is not sufficient, i.e. lower than `thresh_percD.feed` or `thresh_percD.breed`, the habitat is masked (value is set to NaN because the value of the ratio is not representative of the period T_{compo}).

Non-floating composite maps come along with maps representing the percentage of coverage: $Day_{data} / T_{compo} \times 100$. This allows putting composite maps in perspective of the coverage percentage to evaluate its relevance.

4.3.11.5 Zoom on Observations

A zoom around observations of the same day is produced to give an overview of the oceanic context in which a given observation was made. Observations of a same day are presented with the 3-day habitat and with different backgrounds: SST, Chl-a concentration, SST gradient norm, Chl-a gradient norm, SST and Chl-a fronts' central position and `m_dtSST`.

The fronts' central position is computed by: `Habitat_ZoomObservation_v1`, which uses `Habitat_FrontCentralPosition_v1` to compute fronts' central position with a Canny filter from `filt_env_data`. The habitat maps with a shaded background are produced using the function: `Habitat_Map2HabShad_v1`. This function can be run completely independently from the main program since it requires only the intermediate files corresponding to the days where observations are available.

Note: Consequent improvements can be performed to increase the efficiency of this functionality. For instance, in saving the X and Y components of the horizontal gradient of SST and Chl-a concentration instead of saving the norm of the gradient in the intermediate files, the computation of the central position of the front could be performed more efficiently without re-computing the gradient components.

5 Performance of the Habitat Model

5.1 Gain in Term of Coverage

5.1.1 Gain from the Partial Gap Filling

Filling the cloud boundaries allows increasing the coverage percentage. For Modis-Aqua SST and Modis-Aqua Chl-a in 2009, this increase is the following:

As for environmental data:

Variables	Absolute gain (in % of the Mediterranean Sea)	Relative gain between the coverage without and with gap filling (%)
SST	4.2 %	7.7 %
SST Gradient	2.7 %	41.6 %
CHL	2.1 %	7.8 %
CHL Gradient	4.9 %	37.6 %

As for habitat data:

Habitat type(s)	Absolute gain (in % of the Mediterranean Sea)	Relative gain between the coverage without and with gap filling (%)
Feeding	5.7 %	62.1 %
Breeding	5.4 %	8.1 %
Both	5.6 %	57.0 %

The quality of the gap filling technique has been tested on SST and CHL data. The test first consisted in selecting one day with an important original coverage (2003 July 26) and then impairing it with an important cloud mask (cloud mask of 2003 March 7). Finally, the values of the recovered pixels were compared with the original values.

During the test of SST reconstruction more than 12,000 pixels were recovered and compared to the original value. As it can be seen on Figure 15, the error in the recovery process has a positive offset of 0.1 °C, a standard deviation of 0.3 °C and minimum and maximum values of respectively -2.5 °C and 4.0°C.

The offset is due to the way the median is computed in MATLAB. Indeed, when NaN values are present in the window of the median filter, these are replaced by -1. When all the values are sorted, all the -1 (NaN) are located in the lower part of the series, which decrease artificially the median value and so the value of the recovered pixel. Consequently, the difference between the original value and the recovered value of a given pixel tends to be slightly positive.

Note: This last aspect could be improved if a median filter is applied only on finite values. It has not been done in the version 1 of habitat because it would have increased a lot the computation time. The ideal would be to develop a function in C++ or Java which is dealing with the customized median filtering aspects and use it in MATLAB.

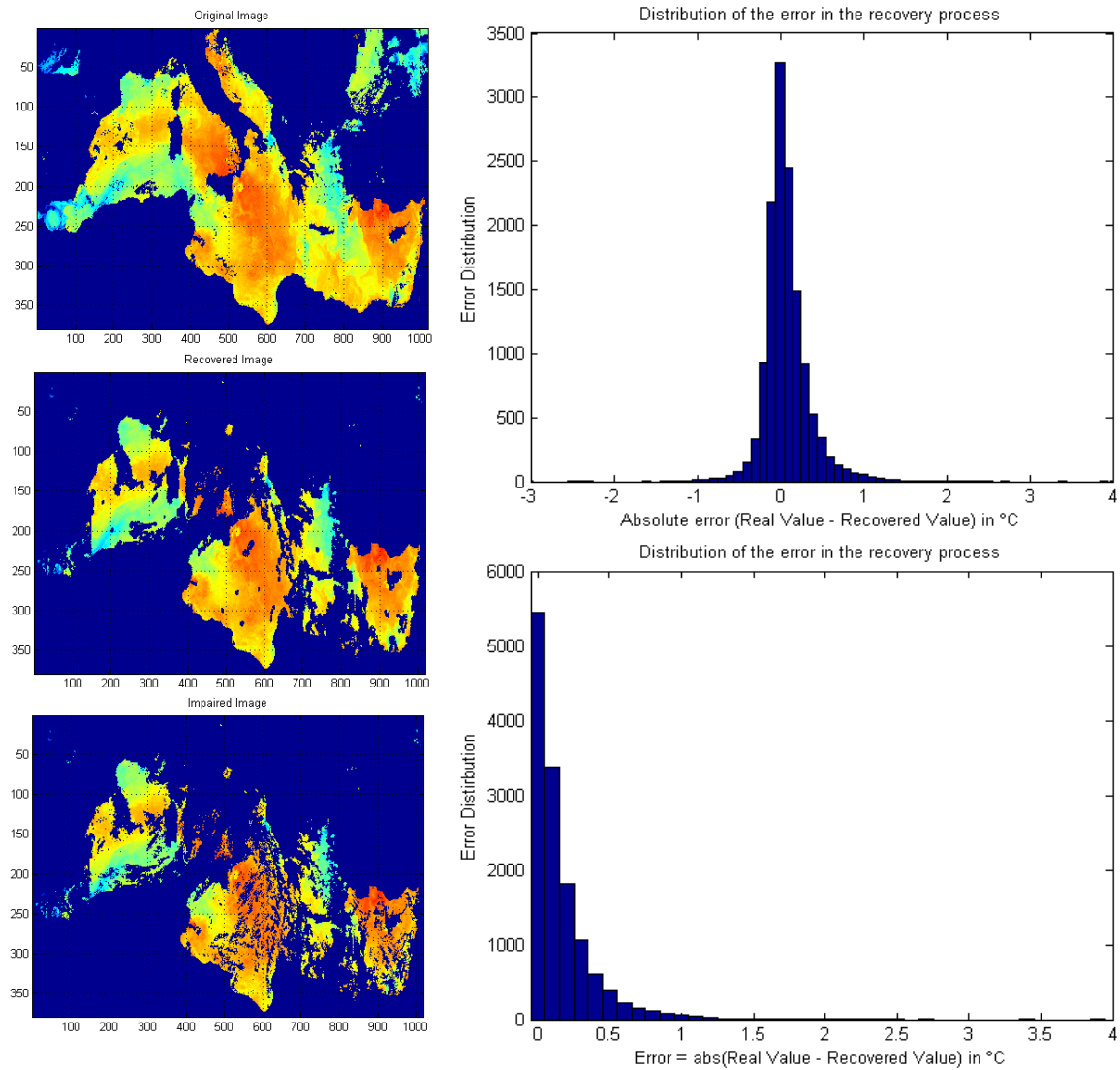


Figure 15: Performance of the partial gap filling. On the left-hand side, from top to bottom are: the original image, the impaired image after gap filling and the impaired before gap filling. The histograms on the right-hand side represent from top to bottom, the error distribution in the recovery process and the distribution of the absolute value of this error.

The average absolute value of the error is 0.2°C (Figure 15). This average error remains within the mean error of the observation by the satellite sensor ($\sim 0.5^{\circ}\text{C}$). The use of such filtering is therefore relevant in term of habitat computation.

The mean value of the error for the Chl-a concentration during the reconstruction is 0.005 mg/m^3 (Figure 16). The mean error of the satellite-derived Chl-a estimate is considered to be on the order of 35% in oceanic waters (case 1). Since the highest values defined for BFT habitat is about 0.4 mg/m^3 , i.e. the highest error in the measurement is about 0.13 mg/m^3 , the gap filling error is about twenty times lower.

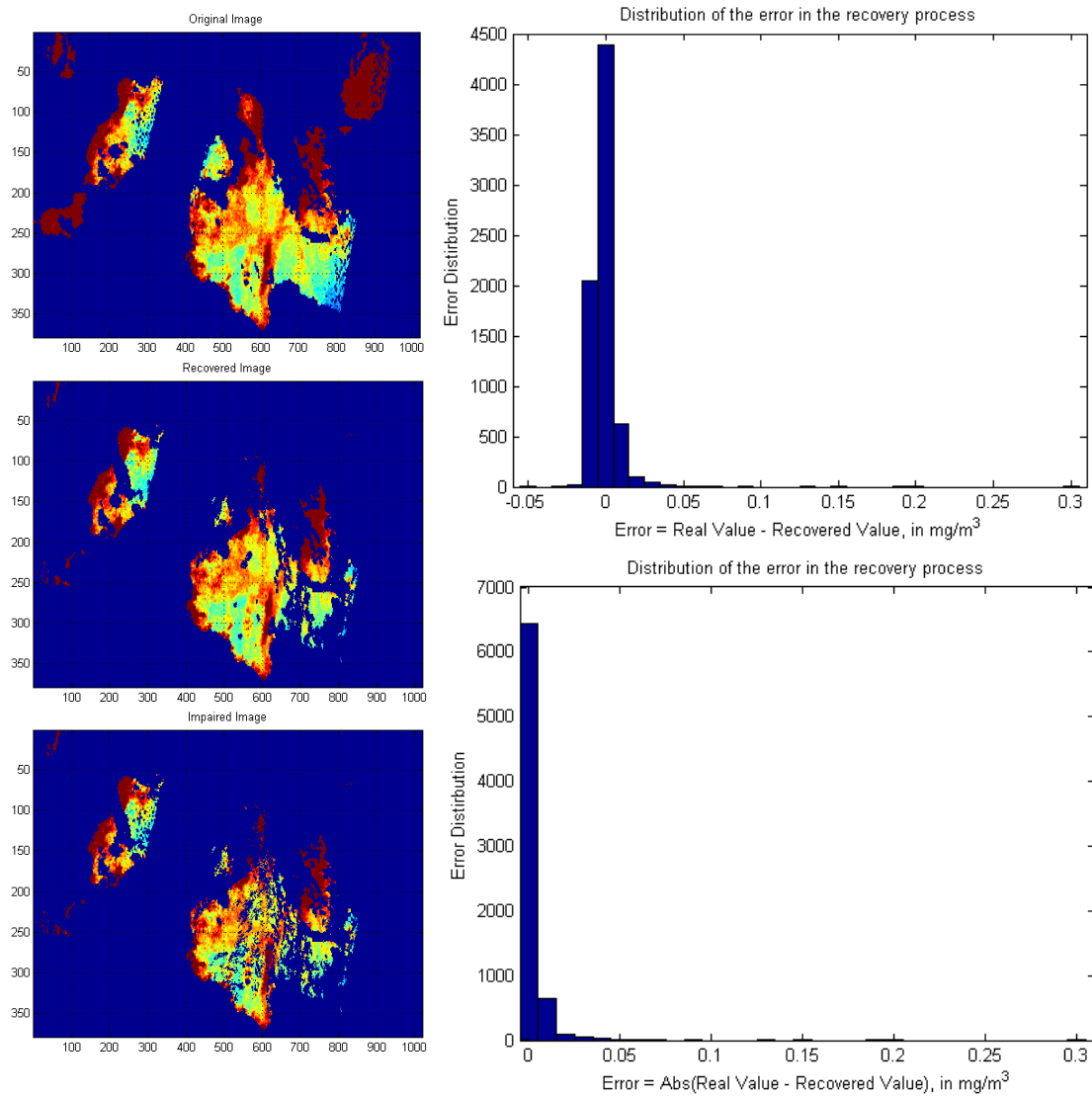


Figure 16: Performance of the partial gap filling of CHL data. On the left-hand side, from top to bottom are: the original image, the impaired image after gap filling and the impaired before gap filling. The histograms on the right-hand side represent from top to bottom, the error distribution in the recovery process, and the distribution of the absolute value of this error.

5.1.2 Gain from the Sensors' Merging

The use of two different couple of sensors contributes to increase the coverage of the estimated habitat. The couple of sensors observe the same area with a fixed time shift (1.5 hours for Chl-a and 3 hours for SST) which allows exploiting changes in the cloud coverage (cloud movement and cloud formation/reduction).

Given the small time interval between the two couple of sensors in comparison to oceanic variability, the observation by both sensors can reasonably be considered as static (one pixel of 4.6 km per 3 hours of maximum shift leads to a velocity of 5.5 m.s^{-1} , to compare with usual maximum current velocity in the Mediterranean Sea of 0.1 m.s^{-1}).

The merging of habitat derived from different sensors shifted in time allows adding on average from 5 % to 10 % of the Mediterranean Sea. Depending on what type of

habitat is considered, this represents a coverage increase from 13% to 66% when comparing with the coverage obtained with Modis-Aqua only.

Below is presented the absolute and relative coverage increase for the year 2003 in the Mediterranean using MAMA and SeMT in comparison to MAMA alone:

Habitat type(s)	Absolute gain (in % of the total Mediterranean Sea)	Relative gain between the coverage without and with gap filling (%)
Feeding	5.2 %	36.1 %
Breeding	8.9 %	13.1 %
Both	9.6 %	66.5 %

5.2 Performance in Term of Habitat Estimate

The performance of the habitat modelling for blue fin tuna and fin back whale with the current parameterization (see Appendix 0) is stated by the following tables.

	BFT(Feeding & Breeding)	FBW(Feeding)
Mean surface of habitat (in % of the Mediterranean Sea)	16+/-8	10.5+/-8
Percentage of observation inside the habitat	42%	28%
Average distance observation-habitat	7km	8.7km
Percentile 80	12km	11.5km
Median (percentile 50)	2km	3km

Table only for BFT to differentiate both types of habitat.

BFT potential habitat	Feeding	Breeding
Mean surface of habitat (in % of the Mediterranean Sea)	14+/-7 (all year long)	2.5+/-2 (Spawning season May-July)
Percentage of observation inside the habitat	55%	30%
Mean distance observation-habitat	4.5km	9km
Percentile 80	7km	18km
Median (percentile 50)	0.02km	4km

Table 3: Performance of the model using 3-day habitat estimates.

6 References

Druon JN, Fromentin JM, Aulanier F and J Heikkonen (*in prep.*). Potential habitat of the Atlantic bluefin tuna in the Mediterranean Sea. *To be submitted to Marine Ecology Progress Series*.

Druon J-N (2010) Habitat Mapping of the Atlantic Bluefin Tuna Derived from Satellite Data: Its Potential as a Tool for the Sustainable Management of Fisheries. *Marine Policy*, 34(2):293-297.

Druon, J.-N. (2009) Environmental analysis of bluefin tuna: identifying its preferred habitat in the Mediterranean Sea. EC-Joint Research Centre, Scientific and Technical Research series – ISSN 1018-5593, ISBN 978-92-79-12613-0, EUR 23790 EN

Appendix - Current parameterization

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                                                                    %
%                               Habitat_Parameter (Version 1)                               %
%                                                                                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%% BFT
if strcmp(species, 'BFT')
    species_1 = 'bluefin tuna';
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Wf_opt = 5.5 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Modis-Aqua SST and CHL parameters -----
    if max(strcmp(sensor, 'MAMA'))
        % BREEDING HABITAT
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        % # of days for breeding computation
        NW.MAMA = 30;
        % minimum fraction of NW days required
        frac_NW.MAMA = 0.29762;
        % other parameters for breeding
        dsstbreed.MAMA = 0.42701; % min. dsst
        chl_breed_min.MAMA = 0.071896; % mgChl/m3
        chl_breed_max.MAMA = 0.15208; % mgChl/m3
        Tminbreed.MAMA = 18.8648; % deg.C
        % FEEDING HABITAT
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        % The Canny filter parameters:
        %     Parameters of edge detecting filters:
        %     X-axis direction filter:
        Nxy.MAMA = 7;
        Nx1.MAMA = Nxy.MAMA;
        Sigmax1.MAMA = 1;
        Nx2.MAMA = Nxy.MAMA;
        Sigmax2.MAMA = 1;
        Theta1.MAMA = pi/2;
        %     Y-axis direction filter:
        Ny1.MAMA = Nxy.MAMA;
        Sigmay1.MAMA = 1;
        Ny2.MAMA = Nxy.MAMA;
        Sigmay2.MAMA = 1;
        Theta2.MAMA = 0;
        % Threshold values for horizontal fronts' filtering (SST and CHL):
        levels.MAMA = [0.11 0.0049194]; % [0.11727 0.0049194]; % deg.C/km and
mgChl/m3/km
        chl_feed_min.MAMA = 0.10332; % mgChl/m3
        chl_feed_max.MAMA = 0.32148; % mgChl/m3
    end % End: Modis-Aqua parameters -----

    % Modis-Terra SST and SeaWiFS CHL parameters -----
    if max(strcmp(sensor, 'SeMT'))
        % BREEDING HABITAT
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        % # of days for breeding computation
        NW.SeMT = 30;
        % minimum fraction of NW days required
        frac_NW.SeMT = 0.30712;
        % other parameters for breeding
        dsstbreed.SeMT = 0.43087; % min. dsst
        chl_breed_min.SeMT = 0.078966; % mgChl/m3
    end
end

```

```

chl_breed_max.SeMT = 0.15625; % mgChl/m3
Tminbreed.SeMT = 17.7191; % deg.C
% FEEDING HABITAT
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The Canny filter parameters:
%   Parameters of edge detecting filters:
%   X-axis direction filter:
Nxy.SeMT = 7;
Nx1.SeMT = Nxy.SeMT;
Sigmax1.SeMT = 1;
Nx2.SeMT = Nxy.SeMT;
Sigmax2.SeMT = 1;
Theta1.SeMT = pi/2;
%   Y-axis direction filter:
Ny1.SeMT = Nxy.SeMT;
Sigmay1.SeMT = 1;
Ny2.SeMT = Nxy.SeMT;
Sigmay2.SeMT = 1;
Theta2.SeMT = 0;
% Threshold values for horizontal fronts' filtering (SST and CHL):
levels.SeMT = [0.11758 0.0041644]; % deg.C/km and mgChl/m3/km
chl_feed_min.SeMT = 0.010542; % mgChl/m3
chl_feed_max.SeMT = 0.31712; % mgChl/m3
end % End: Modis-terra and SeaWiFS parameters -----
end
% ----- End BFT -----

%% FBW
if strcmp(species,'FBW')
    species_1 = 'finback whale';
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Wf_opt = 6 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Modis-Aqua SST and CHL parameters -----
    if max(strcmp(sensor,'MAMA'))
        % BREEDING HABITAT % no computation..... NOT USED AT THE MOMENT!!!
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        % # of days for breeding computation
        NW.MAMA = 1; % ATTENTION: MUST BE 1 if breeding is not computed
        % minimum fraction of NW days required
        frac_NW.MAMA = 0;
        % other parameters for breeding
        dsstbreed.MAMA = 0; % min. dsst
        chl_breed_min.MAMA = 0; % mgChl/m3
        chl_breed_max.MAMA = 0; % mgChl/m3
        Tminbreed.MAMA = 0; % deg.C

        % FEEDING HABITAT
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        % The Canny filter parameters:
        %   Parameters of edge detecting filters:
        %   X-axis direction filter:
        Nxy.MAMA = 7;
        Nx1.MAMA = Nxy.MAMA;
        Sigmax1.MAMA = 1;
        Nx2.MAMA = Nxy.MAMA;
        Sigmax2.MAMA = 1;
        Theta1.MAMA = pi/2;
        %   Y-axis direction filter:
        Ny1.MAMA = Nxy.MAMA;
        Sigmay1.MAMA = 1;
        Ny2.MAMA = Nxy.MAMA;
        Sigmay2.MAMA = 1;
        Theta2.MAMA = 0;
    end
end

```

```

% Threshold values for horizontal fronts' filtering (SST and CHL):
levels.MAMA = [0.11514 0.0040867]; % deg.C and mgChl/m3/km
chl_feed_min.MAMA = 0.11886; % mgChl/m3
chl_feed_max.MAMA = 0.44652; % mgChl/m3
end % End: Modis-Aqua parameters -----

% Modis-Terra SST and SeaWiFS CHL parameters -----
if max(strcmp(sensor, 'SeMT'))
    % BREEDING HABITAT % no computation..... NOT USED AT THE MOMENT!!
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % # of days for breeding computation
    NW.SeMT = 1; % ATTENTION: MUST BE 1 if breeding is not computed
    % minimum fraction of NW days required
    frac_NW.SeMT = 0;
    % other parameters for breeding
    dsstbreed.SeMT = 0; % min. dsst
    chl_breed_min.SeMT = 0; % mgChl/m3
    chl_breed_max.SeMT = 0; % mgChl/m3
    Tminbreed.SeMT = 0; % deg.C
    % FEEDING HABITAT
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % The Canny filter parameters:
    % Parameters of edge detecting filters:
    % X-axis direction filter:
    Nxy.SeMT = 7;
    Nx1.SeMT = Nxy.SeMT;
    Sigmax1.SeMT = 1;
    Nx2.SeMT = Nxy.SeMT;
    Sigmax2.SeMT = 1;
    Theta1.SeMT = pi/2;
    % Y-axis direction filter:
    Ny1.SeMT = Nxy.SeMT;
    Sigmay1.SeMT = 1;
    Ny2.SeMT = Nxy.SeMT;
    Sigmay2.SeMT = 1;
    Theta2.SeMT = 0;

    % Threshold values for horizontal fronts' filtering (SST and CHL):
    levels.SeMT = [0.10518 0.005283]; % deg.C and mgChl/m3/km
    chl_feed_min.SeMT = 0.11488; % mgChl/m3
    chl_feed_max.SeMT = 0.40841; % mgChl/m3
end % End: Modis-terra and SeaWiFS parameters -----
end
% ----- End FBW -----

%% Area Parameters
% cut the area of interest
% Mediterranean Sea
if strcmp(area, 'med'), LATLIMS=[30 45.8]; LONLIMS=[-6 36.5]; end
% North-East Atlantic
if strcmp(area, 'ne_atl'), LATLIMS=[23 48]; LONLIMS=[-38 -1]; end
% Iceland
if strcmp(area, 'iceland'), LATLIMS=[58 70]; LONLIMS=[-31.5 -4]; end
% Malta Tripoli area
if strcmp(area, 'malta'), LATLIMS=[33 36]; LONLIMS=[13 15.5]; end
% Western Indian Ocean
if strcmp(area, 'w_indian'), LATLIMS=[-27.5 -6]; LONLIMS=[35.0 68.0]; end
% Gulf of Mexico and eastern US coast area
if strcmp(area, 'us'), LATLIMS=[20 45]; LONLIMS=[-98 -65]; end
% Northern Europe (Irish Sea, English Channel, North Sea, Baltic Sea)
*
if strcmp(area, 'n_europe'), LATLIMS=[48 61]; LONLIMS=[-10 30]; end

```

```

%% Workspace Settings

% RUN from Linux machine using FISH/STORE/HOME disks
if isunix
    % to store temp result and temp files.
    workdir = [getenv('WORK') '/HABITAT/' species '_HABITAT/'];
    tmplocaldir = ['/tmp/TEMP_HABITAT_',TmStmp,'/']; % tmp directory on the local
disk
    datadir = [getenv('STORE') '/SAT_DATA/'];
end
% RUN from Laptop
if ispc
    [s,r]=dos('net use');
    if (regexpi(r, 'S:') > 0 && exist('D:', 'dir') > 0)
        % from Laptop using FISH disk S: (STEP = 0 or 1)
        datadir = 'K:/SAT_DATA/';
        tmplocaldir = ['D:/TEMP_HABITAT_',TmStmp,'/']; % to store temp result and
temp files.
        workdir = ['S:/HABITAT/',species,'_HABITAT/']; % to build the result
archive.
    else
        % just for STEP=1 and write on laptop disk
        % Copy first the updated MAT files in the following directory!
        tmplocaldir = [getenv('USERPROFILE'),'My Documents/TEMP_HABITAT/'];
        workdir = [getenv('USERPROFILE'),'My
Documents/HABITAT/',species,'_HABITAT/'];
    end
end

% NOT NECESSARY DIRECTLY IN THE FILES IN TEMP_HABITAT % temporay directories for
processing purposes
% tmpdatadir = [tmplocaldir 'TEMP_FRONTS/']; % directory to store locally FRONTS
files
% tmphabitatdir = [tmplocaldir 'TEMP_HABITAT_DATA/']; % directory to store
temporarily habitat data

% temporary local directory to store the results after having been copied
% on the network HDD.
sharedmatdir = [workdir '../SHARED_MAT/',area,'/'];
outdirbothgoogle = [workdir 'GOOGLE_EARTH/BOTH_HABITATS/'];
outdirfronts = [workdir 'SST_CHLa FRONTS/'];
outdirfeed = [workdir 'FEEDING_HABITAT/DAY/'];
outdirfeed15d = [workdir 'FEEDING_HABITAT/15DAY/'];
outdirfeed30d = [workdir 'FEEDING_HABITAT/MONTH/'];
outdirfeed90d = [workdir 'FEEDING_HABITAT/SEASON/'];
outdirfeed300d = [workdir 'FEEDING_HABITAT/ANNUAL/'];
outdirbreed = [workdir 'BREEDING_HABITAT/DAY/'];
outdirbreed15d = [workdir 'BREEDING_HABITAT/15DAY/'];
outdirbreed30d = [workdir 'BREEDING_HABITAT/MONTH/'];
outdirbreed90d = [workdir 'BREEDING_HABITAT/SEASON/'];
outdirbreed300d = [workdir 'BREEDING_HABITAT/ANNUAL/'];
outdirboth = [workdir 'BOTH_HABITAT/DAY/'];
outdirboth3d = [workdir 'BOTH_HABITAT/3DAY/'];
outdirboth7d = [workdir 'BOTH_HABITAT/7DAY/'];
outdirrobs = [workdir 'OBSERVATIONS/'];

% create new directories if needed
[s,mess,messid] = mkdir(sharedmatdir);
[s,mess,messid] = mkdir(tmplocaldir);
[s,mess,messid] = mkdir([workdir,'GOOGLE_EARTH/BOTH_HABITATS/']);
[s,mess,messid] = mkdir([workdir,'CAL_VAL/']);
[s,mess,messid] = mkdir([workdir,'SST_CHLa FRONTS/']);
[s,mess,messid] = mkdir([workdir,'FEEDING_HABITAT/']);

```

```

[s,mess,messid] = mkdir([workdir,'BREEDING_HABITAT/']);
[s,mess,messid] = mkdir([outdirfronts,'MAT/',area]);
[s,mess,messid] = mkdir([outdirbreed,'MAT_',area]);
[s,mess,messid] = mkdir([outdirfeed,'MAT_',area]);
[s,mess,messid] = mkdir([outdirboth,'MAT_',area]);
[s,mess,messid] = mkdir(outdirobs);
for i = 1:length(year)
    [s,mess,messid] = mkdir([outdirfronts,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirfeed,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirfeed15d,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirfeed30d,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirfeed90d,area]);
    [s,mess,messid] = mkdir(outdirfeed300d);
    [s,mess,messid] = mkdir([outdirbreed,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirbreed15d,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirbreed30d,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirbreed90d,area]);
    [s,mess,messid] = mkdir(outdirbreed300d);
    [s,mess,messid] = mkdir([outdirbothgoogle,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirboth,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirboth3d,num2str(year(i)),'_',area]);
    [s,mess,messid] = mkdir([outdirboth7d,num2str(year(i)),'_',area]);
end

%% Satellites' Data Settings
% Original data filename are made out of: prefix yyyyddd suffix

% Modis-Aqua SST
prefix.MAMA.SST = 'A';
suffix.MAMA.SST = '.L3m_DAY_NSST_4';
% Modis-Aqua CHL
prefix.MAMA.CHL = 'A';
suffix.MAMA.CHL = '.L3m_DAY_CHLO_4';
% Modis-Terra SST
prefix.SeMT.SST = 'T';
suffix.SeMT.SST = '.L3m_DAY_NSST_4';
% SeaWiFS CHL
prefix.SeMT.CHL = 'S';
suffix.SeMT.CHL = '.L3m_DAY_CHLO_9';

% Original file where geographic, scaling and no data information can be
% found
AllMissionOriginalFilePath.MAMA.SST = [datadir
'MODIS_AQUA/NSST/A20020012008060.L3m_CU_NSST_4'];
AllMissionOriginalFilePath.SeMT.SST = [datadir
'MODIS_TERRA/NSST/T20000012008060.L3m_CU_NSST_4'];
AllMissionOriginalFilePath.MAMA.CHL = [datadir
'MODIS_AQUA/CHLO/A20021852009365.L3m_CU_CHLO_4'];
AllMissionOriginalFilePath.SeMT.CHL = [datadir
'SeaWiFS/CHLO/S19972472009273.L3m_CU_CHL_chlor_a_9km'];

%% Parameters needed to run the loops over variables
varlist = {'sst' 'chl'};
namelist = {'SEA SURFACE TEMPERATURE' 'CHLOROPHYLL CONCENTRATION' };
unitlist = {' ^oC.km^{ -1}' ' mgChl.m^{ -3}.km^{ -1}' };
dirlist = {'NSST/DAY/' 'CHLO/DAY/' };

%% Plot parameters
% double the character size for plot display when runs on Linux machine
if isunix
    sizechar=2;
else
    sizechar=1;
end

```

```

end

% Screen size in pixels
ScrnSz = get(0,'ScreenSize');
% Area aspect ratio
AspRatio = size(Plt.M,2)/size(Plt.M,1); % Column/lines
% Width and height for simple map figure
map_width = ScrnSz(4)/3*AspRatio;
map_height = ScrnSz(4)/3+100;
% Width and length of double map figure
dblmap_width = ScrnSz(4)/2*AspRatio/3+200;
dblmap_height = ScrnSz(4)/2;

% Non Floating Composites -----
thresh_percD.feed = 10; % Minimum percentage of days needed to compute composite
thresh_percD.breed = 28; % Minimum percentage of days needed to compute composite
if strcmp(area,'med') == 0 % Higher cloud cover if outside med area
    thresh_percD.feed = round(thresh_percD.feed*0.3);
    thresh_percD.breed = round(thresh_percD.breed*0.3);
end

% caxis feeding
caxis_feedhab15 = [0 75];
caxis_feedhab30 = [0 75];
caxis_feedhab90 = [0 75];
caxis_feedhab300 = [0 60];
caxis_feedcov15 = [0 100];
caxis_feedcov30 = [0 100];
caxis_feedcov90 = [0 80];
caxis_feedcov300 = [0 60];

% caxis breeding
caxis_breedhab15 = [0 75];
caxis_breedhab30 = [0 75];
caxis_breedhab90 = [0 30];
caxis_breedhab300 = [0 10];
caxis_breedcov15 = [0 100];
caxis_breedcov30 = [0 100];
caxis_breedcov90 = [0 100];
caxis_breedcov300 = [0 100];

% End: Non Floating Composites -----

%% Front Files Update Parameters

% Last run date
if exist([sharedmatdir,'LastRunDate.mat'],'file')
    load([sharedmatdir,'LastRunDate.mat']);
else
    LastRunDate = now;
end

RmNumDays.MAMA = 20; % Number of days of which fronts files has to be removed
                    % from last run for NRT run
RmNumDays.SeMT = 20;

% initialisation of the index to make the list of modified front files.
i_missfront = 0;

```



```

%% Image Enhancement Parameters
% Order-Gauss Filter
SzOrd = 5; % Size of the order filter
Perc = 50; % Percentage of the order filter
SzGauss = 3; % Size of the lowpass Gaussian filter
SigGauss = 2; % Standard deviation of the lowpass Gaussian filter

%% Zoom on observations parameters
ObsFilePath = [workdir
'../../DATA/',species,'_OBSERVATION/',species,'_observation_all.mat'];
IntermedDir = [outdirfronts,'MAT/',area,'/'];
ZoomSz = [8 4]; % in degrees.

```

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Abstract

This report provides a technical support (documentation) to the use of the habitat model of marine pelagic species. It describes in details the version 1 of the model. It includes data from two couples of satellite sensors for surface temperature and surface chlorophyll content to derive the habitat of bluefin tuna (feeding and spawning) and finback whale (feeding). The model has been calibrated and validated for these species in the Mediterranean Sea.

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